

Ideas and Innovation in East Asia

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Abstract

The generation, diffusion, absorption and application of new technology, knowledge or ideas are crucial drivers of development. This paper surveys the diverse approaches to innovation adopted by East Asian economies, the problems faced and outcomes achieved, as well as possible policy lessons. Knowledge flows from advanced countries remain the primary source of new ideas in developing economies. The authors evaluate the role of three main channels for knowledge flows to East Asia - international trade, acquisition of disembodied knowledge and foreign direct investment. The paper then looks at the exceptionally fast growth in domestic innovation efforts in Korea, Taiwan (China), Singapore and China, drawing on information about R&D as well as original analysis

of patent and patent citation data. Citation analysis shows that while East Asian innovations continue to draw heavily on knowledge flows from the US and Japan, citations to the same or to other East Asian economies are quickly rising, indicating the emergence of national and regional knowledge stocks as a foundation for innovation. A last section pulls together findings about policies and institutions to foster innovation, under three heads: the overall business environment for innovation (macroeconomic stability, financial development, openness, competition, intellectual property rights and the quality of communications infrastructure), human capital development, and government fiscal support for innovation.

This paper—a product of the Chief Economist Office in the World Bank's East Asia and Pacific Region—is part of a larger effort in the Region to better understand the conditions and policies conducive to innovation and productivity growth in East Asia. Policy Research Working Papers are also posted on the Web at <http://econ.worldbank.org>. The author may be contacted at mbrahmbhatt@worldbank.org.

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I Introduction

Many economies in East Asia have achieved unprecedented growth in output and living standards over recent decades. Some have caught up or are fast catching up with the developed world, though it is less clear whether they can sustain the growth momentum, now that they are approaching the world technology frontier. Others remain at middle and low income levels of economic development. Whether they can catch up with and replicate their fast growing neighbors' success remains an open question.

This paper looks at the diverse approaches employed by East Asian economies to foster innovation, the varying outcomes they have achieved and the potential policy lessons from their experience. This focus is in part predicated on modern endogenous growth theory, which regards the generation, diffusion, absorption and application of new technologies, knowledge or ideas as among the crucial drivers of economic growth and development.² We attempt to examine the extent, the modes and other characteristics of innovation in East Asia using a range of quantitative measures to compare East Asia to other developing and developed regions, as well as to contrast the wide range of experiences within East Asia. We also provide a critical survey of selected aspects of the vast and rapidly growing literature on innovation, to place the East Asian experience in the context of key research findings and broader global trends.

We adopt a broad definition of innovation which includes the introduction of new or improved goods, services, production processes and marketing methods, as well as better modes of business organization in general. The basic requirement is that the innovation be new to the firm that adopts it, even though it may not be new in the world at large.³ Viewed in this perspective, the kinds of activities that lead to innovation cover a wide ground. On the one hand they include systematic, long term, large scale Research and Development (R&D) investments, typically undertaken by business firms, resulting in a stream of discoveries that add to the frontiers of global knowledge, that can be patented and which are the principal source of the firm's competitiveness and profitability. On the other, most innovation by firms in developing countries does not entail this kind of advance in the frontier of global knowledge, but, instead,

² Thus Romer (1993) stresses the importance of overcoming 'idea gaps' relative to 'object gaps' in the process of development, that is, of overcoming barriers to the creation and absorption of productive ideas versus gaps in the availability of objects such as factories or raw materials. See also Romer (1990a, 1990b) and Aghion and Howitt (1992, 2005).

³ The OECD's 2005 *Oslo Manual of Guidelines for Collecting and Interpreting Innovation Data* explicitly follows Joseph Schumpeter's pioneering 1934 analysis by defining innovation broadly as "*the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organisation or external relations.*" The basic requirement for an innovation in this approach is that it be *new to the firm* implementing it, including not only products, processes or methods originally developed by the firm but also those adopted from other firms or organizations. *Innovation activities* are defined as "*all scientific, technological, organisational, financial and commercial steps which actually, or are intended to, lead to the implementation of innovations.*" Innovation activities include not only Research and Experimental Development (R&D), but also acquisition of external technology (for example purchases of patents and non-patented inventions, licenses, know-how, trademarks and designs from other firms), acquisition of capital goods, both those embodying improved technological performance and those with no improvement but which are required for the implementation of new or improved products or processes, and a wide range of other activities needed to prepare an innovation, such as industrial design, engineering and set-up, trial production, patent and license work, production start-up and testing. (OECD, 2005).

‘catching up’ to the global frontier, through adoption and adaptation of existing knowledge, most often from abroad.

East Asia provides an ideal laboratory for studying this broad spectrum of innovation activities because of the unusually wide range of economic development levels of countries in the region, extending from high income emerging economies like Korea, Singapore and Taiwan (China), which now conduct formal R&D and patenting at the levels of the most advanced developed countries, to middle income economies like Indonesia or low income economies like Cambodia that conduct very little or none of these formal innovation activities. What is common to most East Asian economies though, is their success in absorbing knowledge from abroad. The paper therefore begins by examining the channels through which economies have drawn on foreign knowledge, drawing in part on the World Bank’s firm level Investment Climate Surveys.

While it is hard to establish causal relationships, a distinctive feature of East Asian economies is their exceptionally high engagement in international trade. The Bank’s investment climate surveys show that firms in low and middle income East Asian economies rate imports of capital equipment as their most important source of new technology. We also survey other potential channels for international technology transfers and spillovers that have been suggested in the literature, including through exports and foreign direct investment. While the econometric evidence is mixed, a rich body of case study literature argues that East Asian firms may have derived significant technological benefits from exports under longer term Original Equipment Manufacturing (OEM) contracts, as part of the global production networks of foreign multinationals (a model of technological development sometimes described as *supplier-oriented industrial upgrading*). East Asian economies have varied more widely in their openness to FDI than they have in their engagement in trade. Here evidence for technology transfers through ‘vertical’ relationships between local firms and MNC affiliates (another form of supplier-oriented upgrading) is more convincing than for other channels that have been suggested.

We then document trends in indigenous knowledge creation within East Asia, using the growth and distribution of R&D and patenting. Over the last decade East Asian R&D spending grew much more than in any other region, but disparities in spending between economies also widened. Newly Industrialized Economies (NIEs) like Korea, Singapore and Taiwan (China) now devote 2 percent or more of GDP to R&D, among the highest in the world, with the business sector generally performing over two thirds of R&D. China has also been rapidly boosting its R&D spending towards an official target of 1.5 percent of GDP. On the other hand middle income economies such as Indonesia, Philippines and Thailand spend a miniscule 0.1-0.2 percent of GDP on R&D. The skewness of the distribution of R&D activity in East Asia is dwarfed only by the uneven distribution of the patents secured by East Asian economies. Patenting per capita in the NIEs has grown at a pace four times that in the developed world, and is now approaching average developed country levels, while, on the other hand, it remains negligible in most middle and low income economies of the region.

The increasing preeminence of the R&D capability of East Asia’s NIEs raises the possibility of increasing technology diffusion within East Asia. We take the hypothesis to a data set of patent citations. As would be expected, East Asian patents continue to draw heavily on knowledge flows from the US and Japan. But citations to other ‘compatriot’ patents from the same East Asian economy or to other East Asian economies are quickly rising, indicating the emergence of East Asian national and regional knowledge stocks which are now providing an indigenous or regional foundation for new innovations and for cross-border knowledge flows.

Several key findings emerge from our analysis of technology transfer and indigenous innovation in East Asia. First, technology transfer from abroad and indigenous R&D complement each other at all levels of income, although the balance between the two may change. Even in poor economies, some indigenous innovation effort increases the country's capacity to absorb knowledge from abroad. No matter which channel or - more accurately - which combination of channels is employed, the extent and quality of technology transfer from abroad is highly dependent on the absorptive or learning capacity of the domestic economy, which in turn depends on the education and training of the labor force, the extent of domestic R&D and domestic innovation effort more generally. Conversely - a point less well known - cutting-edge innovation that advances the global frontier of knowledge itself remains highly dependent on access to the accumulated stock of knowledge worldwide, through technology transfers or knowledge spillovers of various kinds. It seems there are strong positive feedback loops between domestic innovation and acquiring knowledge from abroad, with each being necessary for and enhancing the other.

Second, East Asian experience confirms that sound fundamentals such as macroeconomic stability, financial sector development, protection of property rights and adequate provision of core public goods are as important for innovation as for general investment. In addition, knowledge itself has strong public good characteristics which create a theoretical rationale for more direct government interventions in support of innovation, including not only the creation of a specialized system of intellectual property rights (IPRs), but also public funding for basic research and, possibly, fiscal incentives for business R&D.

The rest of the paper is organized as follows. Section II examines evidence on knowledge adoption and adaptation in East Asia in particular that drawn from the World Bank's Investment Climate Surveys. Section III tracks trends in indigenous knowledge creation within East Asia, in particular the growth and distribution of R&D. We use patents as an indicator of innovation output to investigate the extent East Asia is approaching the world technology frontier in Section IV, which also summarizes results from estimating a knowledge diffusion model using citation data. The last section concludes by drawing implications of policies and institutions that may help foster domestic innovation as well as absorption of knowledge from abroad.

II Absorbing Knowledge from Abroad – International Technology Transfer and Spillovers

Close to 80 percent world R&D is carried out in the developed world. It is thus not surprising that most innovation by firms in developing countries does not entail advances in the frontier of global knowledge, but, instead, catching up to the frontier through adoption and adaptation of existing products, processes and methods which, while they are new to the developing country firm, are not new to the world, typically originating from firms and other innovators in advanced countries.

What is perhaps less well known is that acquisition of knowledge from abroad remains crucial at *all* levels of development. Eaton and Kortum (1996) estimate that foreign sources of technology account for at least 80 percent of domestic productivity growth in most OECD countries, the only exceptions being the US and Japan. Cutting-edge innovation that advances the global frontier of knowledge would itself be difficult without access to the accumulated stock of scientific and technical knowledge worldwide, through technology transfers or knowledge spillovers of various kinds. Bottazzi and Peri (2005) estimate that a 1 percent increase in US R&D leads to a 0.35 percent rise in knowledge creation (patenting) in other OECD countries within 10 years. Access to foreign knowledge in turn depends on (among other things) exposure to and interaction with international scientific, technical and research communities within firms, universities and other private and public bodies, be this through direct exchanges of information or through trade, investment and other international economic transactions.

The first part of this section draws on the World Bank's firm-level Investment Climate Surveys to provide an overview of broadly defined innovation activity among low and middle income economies in East Asia and elsewhere. The section then looks in more detail at some of the principal channels through which countries absorb knowledge from abroad. These include through imports of products that embody new technologies, through purchasing or licensing new technology, and, lastly, through technology transfers and spillovers that might arise through exporting, especially under long term contracts as part of the global production networks of foreign multinationals, or from the local affiliates of multinational firms (foreign direct investment).

A common theme that emerges from this discussion is that, no matter which channel or - more accurately - which combination of channels is employed, the extent and quality of knowledge absorption from abroad is dependent on the absorptive or learning capacity of the domestic economy. This in turn depends on the education and training of the labor force and on the extent and quality of domestic R&D and of the domestic innovation effort more generally. Knowledge absorption from abroad needs a domestic technical capacity which can master, adapt and adjust foreign knowledge, to make it useful for local circumstances. This need arises because much of knowledge, especially at the practical level, is difficult to codify into explicit protocols, instructions or formulas. It is *tacit knowledge*, requiring costly face to face interactions and learning processes to master. As Cohen and Levinthal (1989) point out, R&D itself has two faces: innovation and learning. Domestic R&D not only generates new knowledge but it also enhances the firm's ability to assimilate and exploit existing knowledge. Thus developing country firms are more likely to benefit from FDI spillovers if they conduct some R&D themselves. They are more likely to be selected as suppliers to sophisticated global production networks if they already possess significant in-house design, engineering and other

technical capabilities. Overall, then, it appears that domestic innovation and efforts to acquire knowledge from abroad are mutually supportive activities.

Innovation Outcomes in Developing East Asia: A Broad Perspective

Table 1 presents information from the World Bank’s firm-level Investment Climate Surveys on innovation outcomes in six low and middle income East Asian economies (and for an average for 39-43 other developing economies), showing the proportion of firms that carried out one of ten innovations in the three years preceding the survey. The term “innovation” here follows the broad Schumpeterian sense used by the OECD, as the implementation of any “*new or significantly improved product ...or process*” including new marketing or organizational methods in business practices. The most common forms of innovation among these developing economies include introducing a new product or upgrading an existing product line, as well as introducing a new technology that substantially changes how the main product is produced. On average more than 40 percent of firms had undertaken these activities in both East Asia and elsewhere. The rankings of different types of innovation in East Asia are broadly similar to those elsewhere, with some interesting and statistically significant exceptions. East Asian firms are more likely to upgrade their product lines, perhaps the result of their greater reliance on export markets and the need to respond to the rapidly changing product specifications demanded by foreign buyers. They are also more likely to outsource parts of their business operations, suggesting that firms in the region are more relentless in seeking to cut costs, perhaps reflecting a more competitive environment.

Table 1. Innovation Outcomes and Firm Dynamism (Proportion of Firms in Sample)

	Cambodia 2002	Indonesia 2003	Malaysia 2002	Philippines 2003	Thailand 2004	Vietnam 2005	E.Asia (5/6)	Other (39/43)
(1) New product line	0.53	0.38	0.28	0.49	0.50	0.44	0.44	0.40
(2) Upgraded product line	0.90	0.68	0.49	0.64	0.71	0.66	0.68*	0.56
(3) Intro. new technology (1)	0.60	0.22	0.29	0.42	0.52	0.45	0.44	0.40
(4) Discontinued product line	0.05	0.22	0.20	0.42	0.19	0.19	0.21	0.23
(5) Opened new plant	0.18	0.07	0.11	0.13	0.08		0.11	0.14
(6) Closed existing plant	0.02	0.08	0.05	0.11	0.02		0.06*	0.11
(7) New foreign JV	0.21	0.06	0.05	0.06	0.04	0.06	0.08	0.08
(8) New license agreement	0.21	0.08	0.06	0.13	0.11	0.10	0.13	0.14
(9) Outsourcing	0.33	0.13	0.09	0.21	0.18	0.09	0.17*	0.09
(10) Insourcing	0.41	0.10	0.07	0.14	0.11		0.17	0.10
Core: (1)+(3)	1.13	0.60	0.57	0.91	1.02	0.89	0.88	0.80
Dynamism (Sum of all 10)	3.44	2.02	1.69	2.75	2.46		2.49	2.25

Source: World Bank Investment Climate Surveys. <http://iresearch.worldbank.org/InvestmentClimate/main.html>, Ayyagari et al (2006). (1) New technology that substantially changes how main product is produced. * Difference between means significant at the 5 percent level.

There are also interesting differences between East Asian economies. Even though firms in low income Cambodia do not do formal R&D or make cutting-edge innovations (they received no US patents at all), they are among the most active in adoption and adaptation activities as defined in the Investment Climate Surveys, with over half the firms in the sample introducing or upgrading product lines and production processes. Low income status is clearly

no bar to firm dynamism. Firms in Thailand are also relatively innovative on these measures, while those in Indonesia and Malaysia have been relative laggards.

Ayyagari et al (2006) find several correlates of firm innovation in this sample of developing country firms. First, core innovation outcomes are higher among younger (more recently created) firms, larger firms and firms with high capacity utilization. Second, these broader measures of innovation are not closely related to per capita income, suggesting that, given favorable economic and institutional conditions, firms can be highly innovative in this broad sense in even the poorest economies. (As we show later, formal R&D and sophisticated innovations that lead to patents are different, rising sharply with per capita income). Third, there is a strong negative association between state ownership and innovation, but there is no discernable difference whether a firm is a domestic or foreign privately owned firm. Fourth, there is a strong association between innovation and most types of external financing (equity finance, local or foreign owned commercial bank loans, lease finance, investment funds, trade credits and funds from family and friends).⁴ The study also finds a positive association between innovation and the extent of competition faced by firms.

Table 2. Most Important Source of Technological Innovation – 2003 (% of Firms)

	Cambodia	Indonesia	Malaysia	Philippines	Thailand	Average
Embodied in new machinery	42.1	48.7	49.9	43.0	33.1	43.4
Cooperation with clients	11.9	15.1	8.6	9.7	17.2	12.5
By hiring key personnel	14.5	17.9	11.4	14.2	3.0	12.2
Developed within the firm locally	16.1	4.7	7.2	8.3	19.4	11.1
Transferred from parent	6.0	2.7	11.0	4.3	11.8	7.2
Developed with supplier	1.6	7.0	5.2	5.0	7.2	5.2
Other	7.8	3.9	6.7	15.5	8.2	8.4

Source: World Bank. Investment Climate Surveys. Malaysia is 2002, Thailand is 2004.

Finally the Bank's Investment Climate Surveys also provide a view into the sources of knowledge that firms in these low and middle income economies use to make innovations. Table 2 shows that the single most important source of knowledge for firms in these East Asian economies (cited on average by over 40 percent) was technology embodied in new machinery or equipment (most of which can be assumed to be imported). The next two most cited sources of innovation – those developed in cooperation with client firms and hiring of key personnel were cited by 12-13 percent of firms, while innovations developed or adapted within the firm were cited by only 11-12 percent. These observations provide a good springboard for a more detailed inspection of the methods by which firms absorb knowledge from abroad.

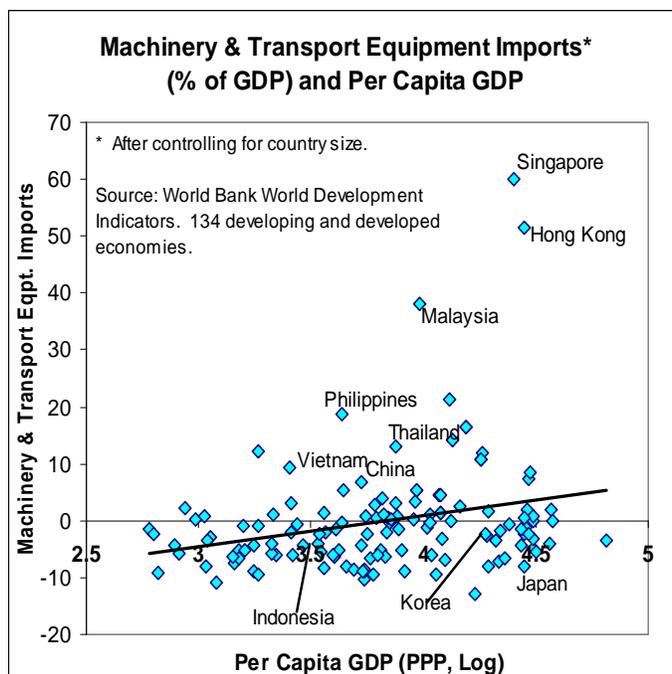
Technology Transfer through Imports

Exceptionally high levels of international trade are a common feature across most East Asian economies, providing a variety of potential channels for acquisition of knowledge. One is through the import of advanced capital equipment embodying new technologies that could either

⁴ The study uses instrumental variables to control for the obvious possibility of reverse causation – that external finance flows to more innovative firms – but finds that variable remains significant.

not have been produced at home at all, or only at much higher cost. Firms in newly industrializing economies like Korea and Taiwan (China) have often strengthened their technological understanding and capabilities by “reverse engineering” of imported capital equipment. Exhibit 1 shows that East Asian ratios to GDP for imports of machinery and transport equipment (including much of what are classified as ‘high technology’ goods) are mostly well above levels associated with other countries at similar per capita income levels.⁵ Table 2 above showed that 3-4 times more firms in East Asian low and middle income economies reported capital equipment purchases as their most important means of acquiring technology.

Exhibit 1



A number of studies have provided indirect evidence for the effectiveness of imports as a channel for knowledge acquisition, observing that R&D in OECD countries has a positive impact on other countries’ total factor productivity, and that this effect tends to rise with the recipient country’s openness to imports. (Coe and Helpman, 1995; Coe, Helpman and Hoffmeister, 1997.) Interestingly, East Asian Newly Industrialized Economies like Hong Kong, Singapore and Korea were found to have elasticities of TFP to foreign R&D stocks generally higher than the average for developing economies. Later studies have mainly confirmed and elaborated these results. Keller (2002) is one of relatively few studies to look jointly at the impact of international trade, foreign

direct investment and disembodied knowledge flows (for example through direct communication) as channels of knowledge flow.⁶ He finds that all three channels are significant, but that imports are the most important, explaining about two thirds of the estimated impacts, while FDI and disembodied flows (as measured) explain about one sixth each on average.⁷

⁵ Geographically small countries tend to export and import more per dollar of GDP than do large ones. Exhibit 1 shows import to GDP ratios after adjustment for this country size effect.

⁶ Keller (2002) proxies disembodied knowledge flows by bilateral language skills – the proportion of the population recipient country who speak the language of the spillover sender country. The study looks at knowledge flows at the industry level among countries at the world’s technology frontier – the G7 industrialized economies.

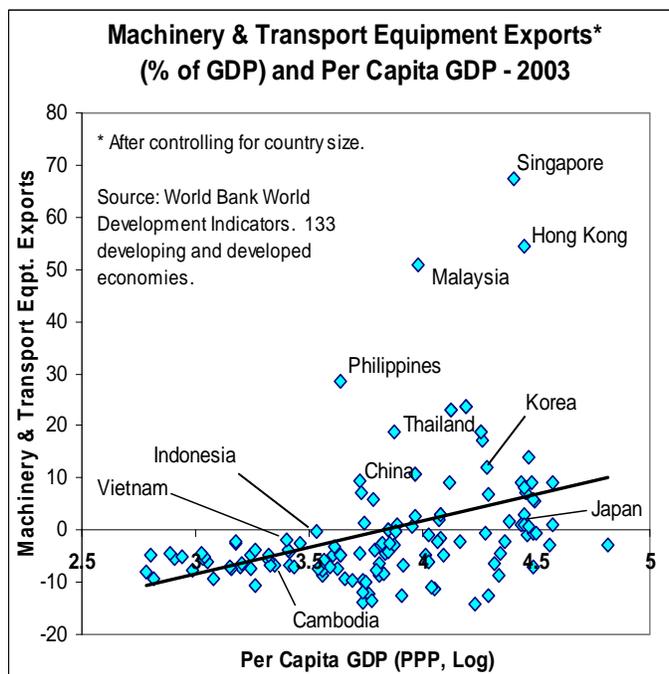
⁷ Among other investigations, Xu and Wang (1999) find that imports of capital equipment provide a better index for measuring R&D spillovers than trade as a whole. Schiff, Wang and Olarreaga (2002) look not only at the impact on developing countries’ productivity of R&D stocks accumulated in the ‘North’, but also those accumulated in the ‘South’, i.e. in developing countries. They find that productivity in developing economies does rise with R&D in other developing economies (and thus with openness to these economies), but that the elasticity is smaller than with respect to R&D in the North. They find that these kinds of South-South R&D spillovers are mostly important for industries that have a low R&D intensity, but not for high R&D intensity industries, which instead benefit most from R&D in the North (and openness to the North).

Learning through Exports?

The rapid, sustained growth of East Asian manufactured (and increasingly 'high tech') exports over recent decades draws attention to the potential role of exports as a channel for technology transfer. At the simplest level exports provide the resources for imports of capital equipment that embody modern technologies. Technology transfer may also be facilitated more directly by interactions between developing country exporters and their developed world customers, who have an incentive to help suppliers upgrade their technical capabilities, productivity and product quality. Exhibit 2 corroborates that East Asian exports of machinery and transport equipment (containing much of what are classified as high technology products) are generally much higher than other economies at similar income levels.

The potential for technology transfer from exporting has been emphasized especially in the case study literature.⁸ Hobday (1995, 2000) stresses the role of Original Equipment

Exhibit 2



Manufacturing (OEM) subcontracting in fostering industrial exports and technology transfer in Korea and Taiwan (China). Under the OEM system the supplier undertakes production (typically for thin profit margins) according to the design specifications of the foreign buyer, which then markets the product under its own brand name through its international distribution channels. OEM production and exports in the NIEs built up rapidly during the 1970s and 1980s. Some 70-80 percent of Korea's electronics exports were under OEM type contracts by 1990, while over 40 percent of Taiwan (China)'s computer hardware exports were of this form at around the same time. Over the past 15 years OEM type contracting has also been central to the enormous expansion of manufactured exports from China, Over the period the OEM model

itself has developed into more complex patterns of global production networking in which first tier suppliers are themselves purchasers from second and third tier suppliers of their own.

The potential benefits of OEM for developing country exporters include achieving economies of scale in production with less risk and cost than attempting to break into global markets on their own, as well as possible technology transfer and training from the customer. By building up its technological capabilities in this way the firm can lay the groundwork for more sophisticated (and profitable) ventures, for example Original Design Manufacturing (ODM), in which the supplier also takes over responsibility for post-conceptual design and development of products sold under the customer's brand, and Original Brand Manufacturing (OBM), when it

⁸ For example, Hobday (1995, 2000), Kim (1997), Matthews and Cho (2000), Kim and Lee (2002) and Nabeshima (2004)

has mastered the entire product cycle of R&D, innovation, design, development, production and marketing under its own brand. This sequential OEM-ODM-OBM path has been labeled the conventional model of *supplier oriented industrial upgrading*. (Sturgeon and Lester, 2004).⁹ Samsung Electronics of Korea is a rare example of a developing country firm that has successfully traveled the whole of this road, building on OEM and technology licensing deals with advanced country MNCs like Sony, Toshiba, Philips and GTE in the 1980s, making huge efforts to build up its design capabilities, R&D and independent brand in the 1990s, till the present, when it has annual R&D expenditures of \$4-5 billion (representing 8-9 percent of sales and employing close to a quarter of the workforce), and has the largest global market share for sales of DRAM and SRAM semiconductors, flash memories, TVs, monitors and LCD panels, as well as the second or third largest market shares for mobile phones and DVD players.¹⁰

Nevertheless, while the case study literature has stressed the opportunities for learning through exports, econometric evidence for this proposition is mixed.¹¹ There is certainly evidence that firms that export generally have significantly higher productivity than those that do not. But this appears to be mainly the result of self selection by more productive firms, which are more likely to undertake the higher fixed costs and rigors of competing in international markets. Clerides, Lach and Tybout (1998), for example, find little evidence for learning effects from exports in plant level data from Colombia, Mexico and Morocco. On the other hand, Kraay (2006) and Aw, Chen and Roberts (1997) do find some evidence that past export experience does help explain current productivity for Chinese and Taiwan (China) firms respectively.

Seeking to explain the somewhat differing results of econometric and case studies, Pack (2006) observes that export data do not typically distinguish exports under long term OEM contracts from other types of exports, so it is perhaps not surprising that econometric studies based on generic export data arrive at only mixed results for export learning effects. There is however a good deal of recent econometric evidence for the existence of technology transfers from multinational firm affiliates in a host country to their local suppliers in the same host country (discussed below). Given this evidence for one form of supplier-oriented industrial upgrading, it may be reasonable to suggest that similar spillovers would also exist for another, that is, for cross-border trade carried out under long term OEM type contracts between an MNC purchaser abroad and developing country OEM exporter firms which are a part of its global production network.

Tybout (2006) also notes that many studies of export learning effects fail to take into account the possibility that future exporters may come into contact with and cooperate with potential foreign customers well *before* export flows actually take place. Kim (1997) describes Samsung's efforts to master production of microwave ovens in the 1970s in response to a prospective order from J.C. Penney, with improvements in productivity preceding actual export flows. This and other case studies suggest that the relationship between exports and productivity is not simply a self-selection story, but also one in which firms make deliberate decisions to improve their productivity in order to serve export markets. Hallward-Driemer, Iarossi and Sokoloff (2002) provide firm level evidence for this hypothesis from five East Asian economies.

⁹ Benefits drawn by developing country firms which act as suppliers to local affiliates of foreign multinationals are another form of supplier-oriented industrial upgrading, a point returned to in the discussion of vertical FDI spillovers below.

¹⁰ Data for 2004.

¹¹ The relevant literature is surveyed in Hoekman and Smarzynska-Javorcik (2006) and Tybout (2006).

Firms that are exporters from the time they are created have significantly higher productivity than firms that only become exporters later, and they also differ systematically in the training of their workforces, the vintage of their capital equipment, the use of outside auditors and other aspects of their production processes and operations. They interpret this finding as evidence that the decision to export encourages firms to undertake productivity enhancing improvements, including, no doubt, in the technologies applied. Hallward-Driemer et al point out that the gap in productivity between firms that began as exporters and others is largest and most significant in lower income economies like Indonesia, Philippines and Thailand, less so in Malaysia and essentially zero in the most developed economy, Korea. They conclude that “to those concerned with policy...the message would be that it is the least developed economies that have the most to gain from measures that would broaden the markets they face”.

Nevertheless, while developing country firms may have most to gain from taking on the challenges of exporting, they may also be the least well equipped to do so. Nabeshima (2004) observes that to be selected as an OEM supplier firms already need to possess production and technological capabilities that allows them to meet demanding quality, cost and delivery requirements. The requirements for attempting the transition to Original Design or Original Brand manufacturing are even greater, helping explain why firms like Samsung are among only very few developing country firms to have made the transition to primary reliance on internal R&D and its own global brands.

Drawing on interviews with lead firms and suppliers in the electronics and auto parts industries, Sturgeon and Lester (2004) suggest that recent trends are raising the economies of scale and technological competencies required for participation in the global production

Table 3
Top 5 Electronic Contract Manufacturers
1994 and 2004. (Revenues in \$Mill.)

1994		2004	
Company	Revenue	Company	Revenue
Sanmina ⁽¹⁾	2363	Flextronics ⁽³⁾	15355
Celestica ⁽²⁾	1989	Hon Hai ⁽⁴⁾	13190
Solectron ⁽¹⁾	1642	Sanmina ⁽¹⁾	12205
Jabil ⁽¹⁾	404	Solectron ⁽¹⁾	11638
Flextronics ⁽³⁾	211	Celestica ⁽²⁾	8840

⁽¹⁾ USA. ⁽²⁾ Canada. ⁽³⁾ Incorporated in Singapore; managed from USA. ⁽⁴⁾ Taiwan (China). Sources: Sturgeon and Lester (2004); Electronic Business September 2005.

networks of multinational companies, putting in question the usefulness of the supplier oriented model for many developing economies. With excellent manufacturing performance and low costs being viewed as widely available and commodified, potential suppliers now also need to provide the lead firm with value-adding capabilities in product and component design, component sourcing, inventory management, testing, packaging and logistics. Increasingly, suppliers also need to be global in scope, able to support their lead firms all over the world. Lead firms are also less inclined to establish long term relationships with suppliers who threaten to turn into competitors, preferring to do business with ‘pure play’ OEM-ODM suppliers.

Reflecting these trends, since the early 1990s lead firms in the electronics industry have outsourced a larger share of their supplier business to a small group of contract manufacturers which operate extensive global production networks to support the worldwide operations of their clients, including both high production volume sites in East Asia, Central and Eastern Europe and Mexico, as well as more specialized sites close to clients in developed economies. (Ernst, 2004). As Table 3 indicates, most of the top contract manufacturers are firms from advanced

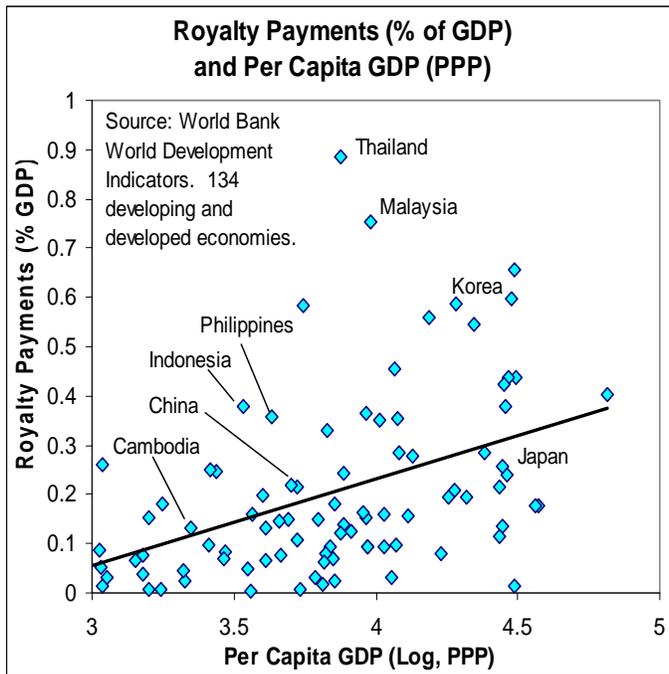
economies, with only a limited number of firms from Taiwan (China) having broken into the top ranks of this business. The 1990s also saw a huge wave of investment in auto assembly and component supply plants in emerging markets, especially in China and elsewhere in East Asia. As in electronics, the major assemblers are increasingly outsourcing to a small number of component suppliers with global reach, typically advanced economy firms like Delphi, Visteon, Bosch, and Denso which take on increasing responsibility for design and supply of the major component modules going into an automobile, and which are able to co-locate near the assembler's worldwide operations. Doner, Noble and Ravenhill (2004, 2006) observe that these assembler strategies are tending to raise barriers to entry for developing country firms aiming to enter the global auto parts industry.

According to these case studies, competitive pressures are raising the technological and scale thresholds required for East Asian firms to participate in global production networks. If in the past low production costs were an adequate entry ticket for participation, today the price of entry also includes more sophisticated learning, innovation and design capabilities.

Technology Licensing and Disembodied Knowledge Flows

Firms can also purchase disembodied external knowledge through acquisition of patents, non-patented inventions, licenses, disclosures of know-how, trademarks, designs, patterns and other consultancy and technological services. Royalty payments abroad provide a rough

Exhibit 3



measure of this form of technology transfer. Exhibit 3 indicates that royalty payments abroad by East Asian economies are also generally much higher relative to other economies at similar income levels. Firms may also derive disembodied knowledge flows through technological spillovers, benefiting from open source information such as scientific, technical and industry journals, informal contacts and communications through networks of researchers and specialists, trade and industry associations, trade fairs.

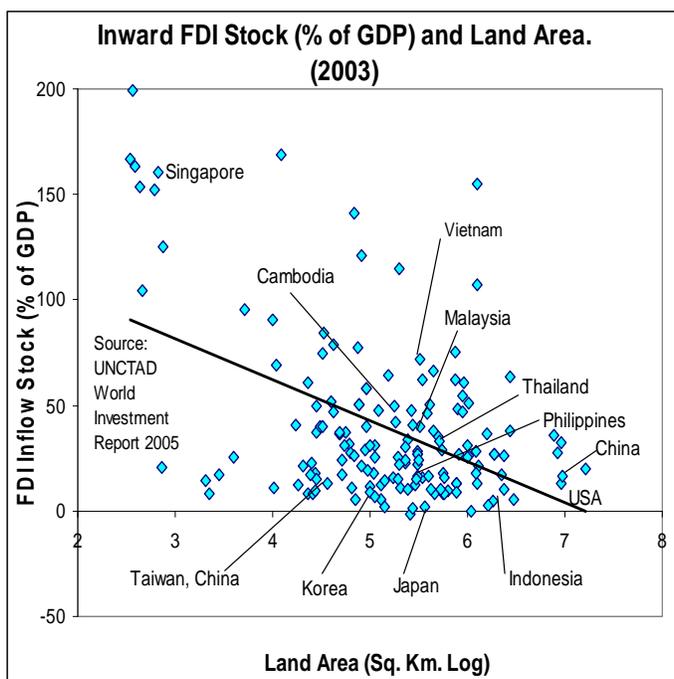
Telecom systems are also an important channel for the flow of disembodied knowledge, as well as for facilitating international trade and coordination of multinational investment activity. The importance of the ICT infrastructure for innovation and

productivity growth is suggested in Wei-Kang Wong (2006). This study looks at the impact of various types of cross-border flows on productivity and growth, including trade, FDI and disembodied knowledge flows, the latter proxied by international telephone traffic. Interestingly, telephone traffic is found to have the most robust positive effect on productivity and income.

Foreign Direct Investment

Historically East Asian economies have shown more differences in their reliance on FDI than they have done on openness to trade or technology licensing, although in recent years there has been some convergence towards more openness to FDI. Historically, Korea and, to a lesser extent, Taiwan (China) have tended to restrict FDI while emphasizing licensing of foreign technology and upgrading of domestic technological capabilities, including through domestic R&D and strengthening of technical education and labor force skills. Singapore, on the other hand, has welcomed FDI, while also fostering domestic technology efforts. China too has drawn heavily on FDI inflows, emphasizing joint ventures, while more recently also emphasizing

Exhibit 4



domestic R&D. Middle income South East Asian economies like Malaysia, Thailand, Indonesia and Philippines (since the 1980s) have also been open to FDI, although, as we show in a later section, the level of indigenous technological effort in these economies (especially R&D) has been limited.¹²

Exhibit 4 shows a scatter plot of countries' accumulated stocks of inward FDI (relative to GDP) versus land area.¹³ Consistent with their past history of relatively restrictive policies on FDI inflows, economies like Japan, Korea and Taiwan (China) have low stocks of inward FDI relative to other economies of comparable geographical size (or per capita income). FDI stocks are also low relative to country size and per capita income in Philippines and Indonesia. On

the other hand, FDI stocks in economies like China, Hong Kong, Singapore, and most middle (and low) income economies in South East Asia are generally at or above the levels predicted by country size or (for the most part) per capita income, reflecting in part more open policies towards FDI. (A partial exception to these observations is that, despite the high absolute flows of FDI to China in recent years, the stock of FDI relative to China's GDP remains low compared to most other economies at a similar per capita income level). It is also interesting to note (Exhibit 5) that while stocks of inward FDI in manufacturing in East Asia are generally higher than in other developing (or developed) regions, FDI in the much larger services sector of these economies is generally much lower.

Theories of the multinational enterprise emphasize its role as an originator of new product and process innovations, managerial expertise, higher quality standards, and access to global export markets. These theories suggest that multinationals opt for foreign direct investment rather than licensing their technology through arms length market transactions

¹² Lall (2003) elaborates the strategies employed by East Asian economies to strengthen industrial competitiveness.

¹³ There is a weak slightly positive correlation between FDI stocks and per capita income across countries. There is however a more significant negative correlation between country size and FDI stocks as a share of GDP.

because of the significant public goods characteristics of knowledge, which prevent the firm from fully protecting its intangible knowledge assets in arms length transactions, and which lead it to deploy those assets within the protective boundaries of its own affiliates, through FDI.¹⁴

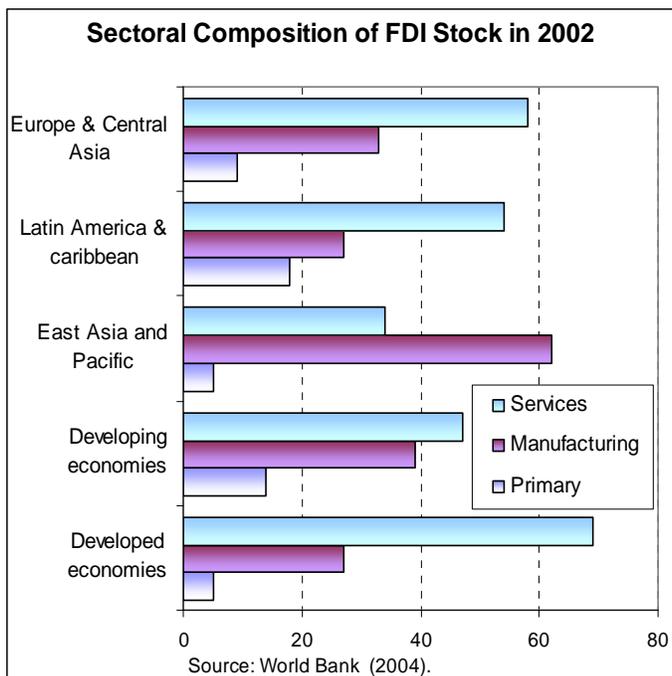
FDI is expected to bring several potential benefits. Foreign affiliates of MNCs have easier access to superior parent company technology and achieve higher productivity in their operations, which, in a competitive environment, translates into higher wages for employees and

higher welfare for consumers through making available better quality goods and services at lower prices. FDI may also enhance productivity in the rest of the economy by increasing competition, or through spillovers of technology and expertise. Here we review evidence for two propositions: does foreign ownership convey productivity benefits for the local firms or operations that are acquired or established by the MNC, and, if these benefits exist, do they “spillover” to other domestic non-acquired firms?

First, does FDI convey large productivity benefits for the local operations that it acquires? There is much evidence that such operations generally have higher labor productivity, total factor productivity and wages than local firms. What has not been clear is whether this superiority is due to restructuring and

infusion of new technology by the new foreign owners, or, instead, it simply reflects foreign firms acquiring already superior local firms. Recent research addresses this question using firm-level data from the Census of Indonesian Manufacturing Plants from 1983 to 1996. (Arnold and Javorik, 2004; World Bank, 2005b).¹⁵ The analysis shows that Indonesian plants receive a rapid and large improvement in total factor productivity from foreign acquisition, averaging about 46 percent. (Exhibit 6). In the 1-2 years after acquisition, the acquired plants experience more rapid growth in output, employment, investment and wages than similar local plants. The proportion of skilled workers in the plant labor force increases, as does export orientation and use of imported intermediates, all of which is consistent with significant plant restructuring after acquisition.

Exhibit 5

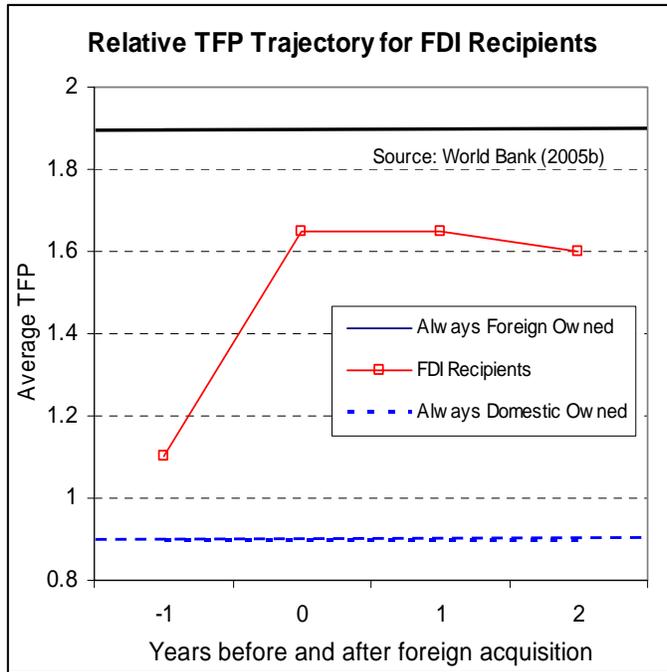


¹⁴ See for example Caves (1996) and Markusen (2002).

¹⁵ Arnold and Javorik (2004) “use a non-parametric matching estimator to calculate the causal effect of foreign ownership on plant productivity. The matching technique creates a missing counterfactual of an acquired firm had it remained under domestic ownership. It does so by pairing up each future acquired plant with a domestic plant from the same sector and year that had observable characteristics very similar to the acquisition target prior to the foreign acquisition. ... The causal effect of foreign ownership is hence estimated by the average divergence of the TFP growth paths between each acquired plant and its matched control plant, starting from the pre-acquisition year.”

Second, does superior technology in MNC affiliates spillover to non-acquired domestic firms? Spillovers are expected to occur when foreign owned firms are unable to fully internalize

Exhibit 6



their superior knowledge. They may occur through local firms copying products, technologies, methods or strategies from MNC affiliates, through observation (*imitation*) or by hiring workers trained by the affiliates (*skill acquisition*). MNC entry could also lead to more *competition* in the host country market, forcing local firms to use existing resources more efficiently or to search for new technologies.¹⁶

Two types of spillovers are relevant: horizontal (or intra-industry) and vertical (or inter-industry) spillovers. Horizontal spillovers are those between competing firms in the same sector. Here foreign firms will have a strong incentive to prevent their superior technology from leaking to local competitors. They may use intellectual property rights, secrecy, paying higher wages or locating in

countries or industries where local firms have limited imitative capacity to prevent spillovers.

Recent research tends to cast doubt on the existence of horizontal spillovers in developing countries. Gorg and Greenaway (2004) review 40 studies on horizontal productivity spillovers in manufacturing industries worldwide and conclude that only 8 find unambiguous evidence of positive horizontal spillovers, mostly for developed economies.¹⁷ On the other hand, several studies using firm-level panel data find evidence of negative effects of FDI on domestic firms, for example Aitken and Harrison's analysis (1999) of Venezuela and Koning's (2001) study of firms in Bulgaria, Romania, and Poland. One suggested explanation for negative effects on the productivity of domestic firms is that greater competition from foreign invested firms reduces the market available to local firms in the short term, forcing them higher up their given cost curves (although in the longer run competition could also force local firms to improve efficiency (shift their cost curves downwards).

The extent of horizontal FDI spillovers tend to depend on the absorptive capacity of the local economy for assimilating new knowledge. Differences in absorptive capacity would help

¹⁶ Das (1987) and Wang and Blomstrom (1992) look at the role of imitation; Haacker (1999), Fosfuri et al. (2001), and Djankov and Hoekman (2000) on skill acquisition; Blomström and Kokko (1998) and Glass and Saggi (2002) on competition. For a general literature review of FDI spillover channels see Gorg and Greenaway (2004).

¹⁷ While 22 studies find positive and significant horizontal spillover effects, Gorg and Greenaway (2004) challenge the results of the 14 which do not use panel data, because such studies are unable to deal with problems of reverse causality. Haskel, Pereira and Slaughter (2002) and Griffith, Redding and Simpson (2003) find small but significant effects for the UK, while Keller and Yeaple (2003) find large, significant ones for the US. Javorcik and Spatareanu (2003) find evidence for horizontal spillovers in Romania.

explain why there is more evidence for horizontal spillovers in developed than in developing economies. Glass and Saggi (1998) find that the greater the technology gap between local and foreign firms, the lower the quality of technology transferred and the lower the potential for spillovers. Kokko et al. (1996) find that in Uruguay there were productivity spillovers to domestic firms with moderate technology gaps but not where the gap was large. Borensztein et al. (1998) and Lipsey (2000) emphasize the need to improve educational capacity in the host economy as a means of strengthening absorptive capacity to incorporate positive spillovers. Kinoshita (2001) finds that in the Czech Republic it is only domestic firms that undertake their own R&D that enjoy horizontal FDI spillovers. Further, distinguishing between ‘the two faces of R&D’ analyzed by Cohen and Levinthal (1989), Kinoshita finds that R&D performing domestic Czech firms benefit not only from innovations produced by that R&D, but also by being better able to learn and absorb knowledge from the outside. This learning effect is several times larger than the own-innovation effect.

Todo and Miyamoto (2006) observe that the extent of horizontal FDI spillovers to domestic firms also depends on the level of R&D undertaken in the host country by foreign firms. The employees of foreign affiliates that perform local R&D are likely to learn more than those in foreign firms that do not, and this knowledge can diffuse to local firms through job turnover, work-related discussions and so on. They find that domestic Indonesian firms in 1994-97 received positive spillovers only from R&D performing foreign firms, but none from non-R&D performing foreign firms. Taken together, the Kinoshita and Todo and Miyamoto studies suggest that domestic ‘in-country’ R&D may be important both for foreign affiliates to generate spillovers and also for domestic firms to absorb such spillovers.

In contrast to the case of horizontal spillovers, foreign firms are likely to be less concerned about or may have a positive incentive to transfer knowledge to their local suppliers or customers through vertical linkages. As with OEM type supplier-customer relationships, these vertical or inter-industry knowledge flows, can take place through direct knowledge transfer, for example through training programs, technical support and collaboration on production and design issues, indirectly through movement of workers between customers and suppliers or simply through higher standards for product quality and on-time delivery, that provide an incentive to domestic suppliers to upgrade their technology. (Local suppliers may also reap the benefits of economies of scale because of increased demand for intermediate products from new multinational customers, although this is not a knowledge transfer in the strict sense).

Blalock and Gertler (2004) find strong support for vertical technology transfers from MNC customers to local suppliers in Indonesia, as does Javorcik (2004) in Lithuania. Saggi (2002) finds that Mexican maquiladoras which began as producers of labor-intensive products later adopted more sophisticated production techniques from their US customers. The size of the effects is generally meaningful. Javorcik (2004) finds that a one-standard deviation increase in foreign presence in the purchasing sector of the economy in Lithuania is associated with a 15 percent rise in output of local firms in supplying sectors. However, as noted in the earlier discussion of OEM type contracts, the potential for vertical transfers is conditional to some extent on domestic firms already having sufficient technological capabilities to meet demanding quality, cost and delivery requirements and be chosen as suppliers for MNC affiliates in the first place, as well as to be capable of technological learning through vertical spillovers once they are chosen. Blalock and Gertler (2004) find, for example, that it is domestic Indonesian firms with high levels of human capital that are the prime beneficiaries of vertical knowledge transfers.

III R&D in East Asia

Total world spending on R&D amounted to \$830 billion in PPP terms in 2002¹⁸ of which some 78 percent was performed by developed countries, much higher than their 59 percent share in world GDP (in PPP terms). That proportion has fallen over the last decade, however, as developing or emerging economies raised their share from 13 percent in 1992 to 22 percent in 2002. East Asia has been at the heart of the rise in developing country R&D, contributing almost three quarters of the increase and quintupling over the decade (in nominal terms) to reach \$112 billion in 2002 or 13.5 percent of the world total. R&D intensity in East Asia – the ratio of R&D spending to GDP – rose from 0.7 percent in 1992 to 1.2 percent in 2002.

As Table 4 indicates, however, East Asian economies differ widely in R&D performance. Korea, Singapore and Taiwan (China) now devote 2.2-2.5 percent of GDP to R&D spending, comparable to levels in the US and the upper end of the scale among developed economies. On the other hand R&D spending in economies such as Indonesia, Philippines and Thailand is only

Table 4. Research and Development Expenditures

	R&D Spending 2002		R&D as % GDP*	
	US\$ Bill. (PPP)	% of World	1992	2002
East Asia	111.7	13.5	0.7	1.2
NIEs.	36.4	4.4	1.6	2.2
Hong Kong	1.1	0.1	0.3 (b)	0.6
Korea	20.8	2.5	1.9	2.5
Singapore	2.2	0.3	1.2	2.2
Taiwan, China	12.2	1.5	1.8	2.3
South East Asia	3.3	0.4	0.1	0.2
Indonesia	0.3	0.0	0.1 (c)	0.1 (a)
Malaysia	1.5	0.2	0.4	0.7
Philippines	0.4	0.0	0.2	0.1
Thailand	1.1	0.1	0.2	0.2
China	72.0	8.7	0.8	1.2
World	829.9	100.0	1.7	1.7
Developed	645.8	77.8	2.3	2.3
Japan	106.4	12.8	2.9	3.1
USA	275.1	33.1	2.6	2.6
Developing	184.1	22.1	0.6	0.9
Latin America	21.7	2.6	0.5	0.6
Emerg. Europe	30.3	3.7	1.0	1.2

Source: UNESCO (2004, 2006). (a) 2001 (b) 1995 (c) 1994.

*Regional data are sum of R&D divided by sum of PPP GDP.

0.1-0.2 percent of GDP, among the lowest of all economies for which we have data. In between these two extremes is China, where R&D spending risen at 20 percent a year over the last decade to reach 1.4 percent of GDP by 2004, or \$109 billion in PPP terms.¹⁹ R&D spending in Malaysia also accelerated after the mid 1990s, reaching 0.7 percent of GDP by 2002.

In East Asia, as elsewhere, richer countries like Korea tend to have much higher R&D intensities than poorer ones like Indonesia. Exhibit 7 shows a scatter plot of panel data for R&D intensity and per capita GDP for a sample of developed and developing economies between the mid 1970s and the early to mid 2000s. R&D intensity not only increases with per capita GDP but does so at an

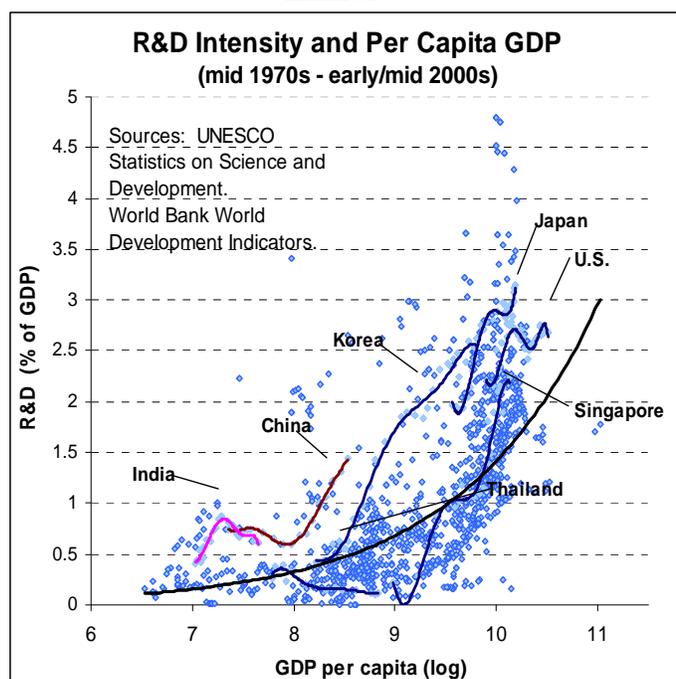
¹⁸ UNESCO (2005, 2006). There is R&D data available for numbers of economies through 2004 or even 2005. But 2002 seems to be the most recent year for which there is comprehensive data for the world as a whole.

¹⁹ It is worth noting that the absolute value of China's R&D in PPP (purchasing power parity) terms is particularly affected by the unusually large disparity between its PPP exchange rate (as calculated by the World Bank and other researchers) and its market exchange rate. Thus China's R&D expenditures in 2004 at market exchange rates were, according to data from UNESCO (2006), \$23.8 billion, or only 21 percent of the PPP figure. By comparison Korea's R&D spending in 2003 was \$22.8 billion in PPP terms and \$16 billion at market exchange rates, or 70 percent of the PPP figure. In Malaysia R&D at market rates was 42 percent of R&D in PPP terms. Note, however, that while this issue is relevant for measuring absolute levels of R&D, it does not affect R&D intensity (the ratio of R&D to GDP), since both the numerator and denominator of that ratio use the same conversion rate.

accelerating pace. As Exhibit 7 also indicates, the trajectories of R&D intensity in several East Asian economies show persistent deviations from the levels suggested by per capita GDP alone. R&D intensity in Korea, China and Taiwan (China) has run at levels twice those suggested by income. On the other hand R&D intensity in Indonesia, Philippines and Thailand has systematically undershot the estimated average relationship over a long period (both before and after the financial crisis of the late 1990s).

Research at the World Bank by Lederman and Maloney (2003) – one of only a few studies to look at R&D in developing countries – finds that policies and institutions play an important role in explaining these systematic deviations (while structural differences such the size of the economy, the size of the labor force and the relative abundance of natural resources do not).

Exhibit 7



In common with other types of investment, R&D intensity declines with higher real interest rates and greater macroeconomic volatility. It increases with greater financial depth and stronger intellectual property rights, as well as with subjective measures of the quality of research institutions such as universities and public research centers, and the quality of collaboration between these institutions and the private sector. The last section of this paper reviews how East Asian economies rank on these economic and institutional correlates of R&D intensity and innovation, finding marked differences between high and low R&D performers.²⁰

Are these large differences in R&D performance significant for economic performance? Is formal R&D important only for a few advanced economies like

Korea, while most developing countries need only focus on absorbing advanced knowledge from abroad, for example through openness to trade and foreign investment? The study by Lederman and Maloney (2003) also estimates the impact of R&D intensity on total factor productivity growth for a sample of both developed and developing economies. They find that a one percentage point increase in R&D intensity is associated with a 0.78 percent rise in TFP growth – in effect a 78 percent social rate of return on R&D investment.²¹ Earlier studies for the United States and other OECD countries also find high social rates of return on R&D.²² Compared to

²⁰ Jaumotte and Pain (2005a) also provide an extensive analysis of the determinants of business sector R&D in the OECD countries. Among the more important influences on business R&D are economic framework variables such as the user cost of capital, corporate profits, financial development, international trade openness and product market restrictions (lack of competition). Among significant national innovation system variables are government subsidies for business R&D (although only in some conditions), the level of non-business R&D (largely in universities and non-profit bodies), business-academic linkages and a lagged term for the number of scientists and engineers.

²¹ The term social here indicates that the returns measured include not only private returns to the firm making the R&D investment, but also the benefits for others generated by R&D spillovers or externalities.

²² For example Griliches (1992, 1995) and Jones and Williams (1998).

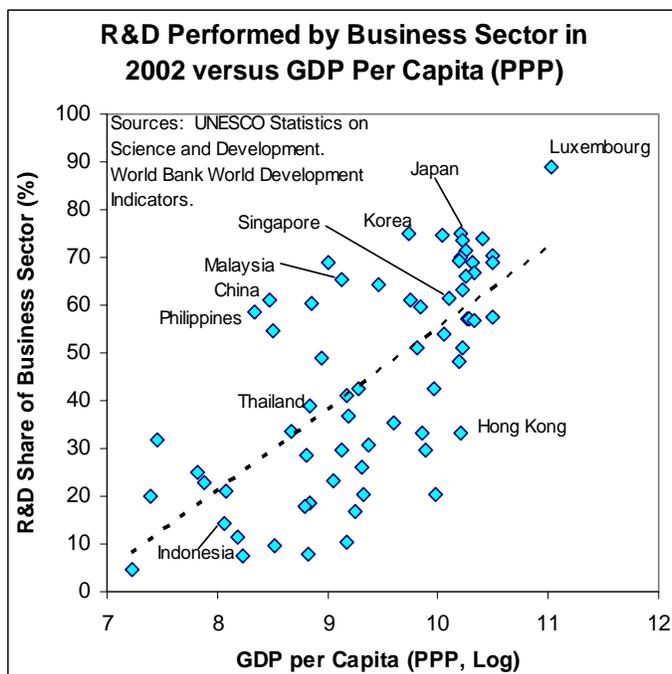
the prevailing costs of capital, these returns imply that actual levels of R&D are only a fraction of socially optimal levels. Interestingly, the study finds that returns to R&D *fall* substantially with the level of per capita income – in other words returns are *higher* in poor countries than in rich ones. This result is consistent with the intuition that a dollar of R&D should be more valuable in poor countries that are far from the technological frontier than in advanced countries that must focus on cutting edge innovations that shift the frontier forward. This is likely to especially be the case for R&D expenditures devoted to adapting foreign technologies into forms useful in the local environment.

To summarize, there is some evidence that domestic R&D benefits not only rich economies but can also benefit poor ones. Buttressing a point made earlier, poor economies can especially benefit from development expenditures that facilitate absorption of knowledge from abroad. Although potential returns to R&D in poor countries are high, R&D in these economies is held back by macroeconomic instability, underdeveloped financial systems, weak intellectual property rights and low quality public research institutions.

R&D by Sector of Performance and Funding

The business sector in East Asia plays an unusually big role in R&D.²³ Table 5 below shows that the median share of business R&D among the main East Asian economies is a little over 60 percent, about the same as for developed economies and higher than Latin America (around 30 percent) or Emerging Europe (a little over 40 percent). Exhibit 8 indicates that the business share in R&D performed generally rises with per capita income.

Exhibit 8



However several East Asian economies – China, Korea, Malaysia and Philippines - have much higher business shares than would be suggested by per capita GDP alone.²⁴ Table 5 indicates that for the East Asia region over all, the median proportion of R&D performed by government – around 22 percent – is much higher than among developed economies, while the proportion performed in higher education is much lower. This may point to a need to strengthen the role of research at East Asian universities, particularly among the newly industrialized economies (NIEs).

Turning to the financing of R&D, the median share of government funding for R&D in East Asia is about one third, roughly the same as among developed

²³ Business R&D here includes domestic private firms, public sector firms and foreign affiliates operating in the country. Government R&D refers to executive branch organizations not engaged in production.

²⁴ Hong Kong is an outlier in the other direction: R&D intensity and the proportion of R&D performed by business and government are low for its level of per capita income, with the bulk of R&D occurring in higher education.

economies. The proportion of R&D funded by the business sector also tends to be quite close to the proportion it performs. Two exceptions are Malaysia and Singapore, where the proportion of R&D performed by business is significantly higher than the proportion it finances, indicating significant levels of government funding for R&D performed in the business sector. (Table 5 does not encompass tax incentives for business R&D, another widely used policy instrument).

Does one type of R&D contribute more to growth than another? Most of the evidence relates to developed economies, but it is informative. Guellec and Pottelsberge de la Potterie (2004) look at the long term impact of business sector R&D, public R&D (defined to include R&D performed by universities) and R&D performed in the outside world on total factor productivity growth in 16 OECD economies. (R&D in the outside world is introduced to capture the effect of international technology spillovers and transfers). Over the period 1980-98 they find the elasticity of productivity with respect to the stocks of business and public R&D to be broadly the same. Crucially for developing countries, the stock of foreign R&D appears to have an impact 2-3 times as large as domestic business or public R&D, underlining the importance of openness to and capacity to absorb international knowledge.

Table 5. R&D by Sector of Performance and Funding *

	Sector of Performance			Sector of Funding		
	Business	Govt.	Higher Educ.	Business	Govt.	Higher Educ.
East Asia	62.2	21.7	14.4	54.3	35.2	2.3
NIEs	63.0	11.7	18.8	58.7	35.9	1.7
Hong Kong	33.2	3.1	63.6	35.3	62.8	0.2
Korea	76.1	12.6	10.1	74.0	23.9	1.7
Singapore	63.8	10.9	25.4	54.3	36.6	2.3
Taiwan, China	62.2	24.8	12.3	63.1	35.2	0.0
S.E. Asia	51.3	22.1	15.7	46.6	35.4	6.2
Indonesia	14.3	81.1	4.6	14.7	84.5	0.2
Malaysia	65.3	20.3	14.4	51.5	32.1	4.9
Philippines	58.6	21.7	17.0	59.7	24.6	7.5
Thailand	43.9	22.5	31.0	41.8	38.6	15.1
China	62.4	27.1	10.5	60.1	29.9	..
Developed (21)	62.9	13.3	27.0	49.2	33.6	2.1
Japan	75.0	9.3	13.7	74.5	17.7	6.3
USA	70.1	12.2	13.6	63.7	31.0	..
Latin Amer. (11)	29.0	27.2	32.7	32.9	37.3	27.4
Emerg.Europe (9)	42.7	29.8	20.1	38.3	54.2	0.5

Source: UNESCO Science & Technology Statistics May 2006.
 * For 2002-05, latest available year. Medians for regions and sub-regions.

What conditions might affect the impact of each type of R&D has on growth? A key finding by Guellec and Pottelsberge de la Potterie is that a higher current *flow* of business R&D increases the economy's ability to absorb benefits from the accumulated *stocks* of all types of R&D, business, public and foreign. In other words, higher current business R&D by domestic firms not only increases their ability to absorb the results of past and present R&D by other domestic firms, it also enhance firms' ability to access knowledge created by the public sector and – crucially for developing countries – to access foreign knowledge. Another interesting finding is that foreign R&D appears to benefit small economies more than large ones.

IV Advancing the Global Frontier: Patenting in East Asia

Just as R&D expenditure provides a partial measure of the resources devoted to innovation, so patents and patent citations provide a valuable though partial view of an economy's innovation outputs. The view is partial because patents – at least in theory - focus only on those innovations that advance the frontier of global knowledge. They give an inventor a temporary legal monopoly over the exploitation of the invention in question, being a device to address some of the problems deriving from the non-excludability or non-appropriability characteristics of knowledge. To receive this temporary monopoly (in itself a costly economic distortion), an invention must typically satisfy requirements of novelty and non-obviousness, which require innovations to make a substantial advance over existing knowledge.²⁵

Most innovation in developing countries however involves adoption and adaptation of existing knowledge, mostly derived from abroad, a topic studied in Section II above. Nevertheless, patentable innovations are of growing importance in East Asia, where several advanced economies now patent at around the same rate as advanced economies. This section looks at patenting in East Asia, using (in common with many studies in this area) patents granted by the US Patent and Trademark Office (USPTO).²⁶ It then considers factors determining patenting, the technology areas in which East Asian patenting is concentrated, and the quality of patenting in the region. Finally, we use patent citations to study flows of knowledge within East Asia and between East Asia and the rest of the world.

Patenting in East Asia

The number of patents granted to East Asian economies averaged some 12108 per year in 2000-04, more than five times the number a decade earlier, in 1990-04. (Table 6). Over the same period the number of patents registered by selected Latin American countries increased from 173 to 368. Table 6 also shows patents relative to population (patents per 100,000 people). In the early 1990s the number of patents per 100,000 people in East Asia – 0.14 – was 2-3 times levels in Latin America and Emerging Europe. By 2000-04, East Asian patents per capita had risen to 0.72, some 6-9 times levels in the other two regions. The vast majority of these patents are

²⁵ Note the the OECD's definition of innovation in Footnote 2 above. Scotchmer (2004) provides a non-technical primer of intellectual property law. Issues and pitfalls in the use of patents as innovation indicators are discussed in Hall et al (2001), Jaffe and Trajtenberg (2002) and Jaffe and Lerner (2004). Firms may also make a strategic choice to protect inventions by other means, for example secrecy, lead times, first mover advantages like moving down the learning curve, and provision of sales and manufacturing services that complement the innovation. Levin et al (1987) and Cohen, Nelson and Walsh (2002) document the importance for US firms of these other methods.

²⁶ This discussion draws on the NBER Patent Citation Database (<http://www.nber.org/patent/>), described in Hall, Jaffe and Trajtenberg, (2001), updated through 2002 by Bronwyn Hall (<http://emlab.berkeley.edu/users/bhhall/index.html>) and through 2004 by Albert Hu. (Hu, 2006). The use of US patents may be justified by the fact that creators of commercially valuable inventions have a strong incentive to take out a patent in the US., given its position as the largest market in the world. Close to 50 percent of patents granted by the USPTO in 2000-04 were to foreigners. Nevertheless, there is a large home bias in patenting (inventors are more likely to patent in their home jurisdiction than elsewhere) and inventors in different economies may also face different incentives to patent in the US (for example depending on the level of exports to the US). These factors, could introduce biases that need to be adjusted for. We concentrate on patents and patent citations for seven East Asian economies: China, Hong Kong, Korea, Malaysia, Philippines, Singapore, Taiwan (China) and Thailand, together with two of their largest economic partners, the United States and Japan.

generated by the NIEs, Taiwan (China) and Korea in particular, which by 2004 had become the 4th and 5th biggest recipients of USPTO patents in the world, after the US, Japan and Germany.

Table 6. USPTO Patents Granted *

	Number of Patents		Patents per 100000 People		
	1990-04	2000-04	1990-04	2000-04	% Change
East Asia (9)	2239	12108	0.14	0.72	17.6
NIEs	2159	11601	2.93	14.74	17.5
Hong Kong	184	616	3.15	9.32	11.4
Korea	633	4009	1.44	8.67	19.7
Singapore	36	382	1.09	9.87	24.6
Taiwan, China	1307	6593	6.30	30.17	17.0
S.E. Asia	31	140	0.01	0.04	15.3
Indonesia	6	15	0.00	0.01	8.8
Malaysia	13	64	0.07	0.28	15.3
Philippines	6	18	0.01	0.02	10.4
Thailand	6	43	0.01	0.07	20.9
China	48	368	0.00	0.03	22.9
World	107361	182523	1.98	2.95	4.1
Developed (21)	104170	168017	12.88	19.58	4.3
Japan	22647	35687	18.23	28.54	4.6
USA	59024	97104	23.00	33.56	3.9
Developing					
Latin Amer. (11)	173	368	0.04	0.08	6.3
Emerg.Europe (9)	205	348	0.07	0.12	5.6

Source: US Patent and Trademark Office. * Annual averages.

As with R&D, there is also a wide variation in patenting across East Asia. Taiwan (China) now generates some 30 patents per 100,000 people, about as many as Japan and the United States, the best performers among the developed economies. Korea, Hong Kong and Singapore generate around 8-10 patents per capita per year, similar to the performance of the developed OECD countries in the mid 1980s, although only about half the average OECD level today. Further down the scale, Malaysia generates 0.2-0.3 patents per capita, similar to Korea in the mid 1980s. Finally, countries such as China, Indonesia, Philippines and Thailand bring up the rear with patents per capita in the 0.01-0.07 range, although patenting in China is rising very rapidly from a low base.²⁷

Exhibits 9 and 10 show a scatter diagram of patents per capita versus per capita income (in PPP terms), using panel data for 1977-2004. (The sample is shown in two exhibits, to permit display of greater detail at different scales). As with R&D intensity, patents per capita tend to rise much more than proportionately to per capita income – 7-8 times more in this case. Thus patents per capita in Singapore are 30 times those in Malaysia, even though Singapore's per capita income (in PPP terms) is only about 3 times higher than Malaysia's. The exhibits pick out the trajectories of patents and income for individual countries over time. Exhibit 3 shows that

²⁷ Hu and Jefferson (2005) suggest several reasons for the acceleration in Chinese patenting: (i) the acceleration in China's R&D spending noted above; (ii) strengthening of China's Patent Law in 1992 and 2000; (iii) the vast influx of foreign direct investment to China, which has greatly increased the market value of intellectual property for both foreign and domestic firms; (iv) the rapid relative growth of 'complex industries' like electronics and machinery, which involve many separately patentable sub-products and processes; (v) the acceleration of enterprise reform after the mid 1990s, which has greatly strengthened private property rights vis-à-vis state owned enterprises.

East Asian NIEs such as Korea and Singapore have generated patents per capita much higher than predicted by their income levels alone, in much the same way as their R&D. Interestingly, in recent years patenting in Hong Kong has also exceeded predicted levels, even though its R&D is much lower than predicted. Exhibit 10 shows that Malaysia and China have generally innovated at around the levels predicted by income, although China's patenting has accelerated to levels higher than predicted by income in recent years. Indonesia, Philippines and Thailand, on the other hand, have performed below the predicted level, in line with their R&D underperformance.

Exhibit 9

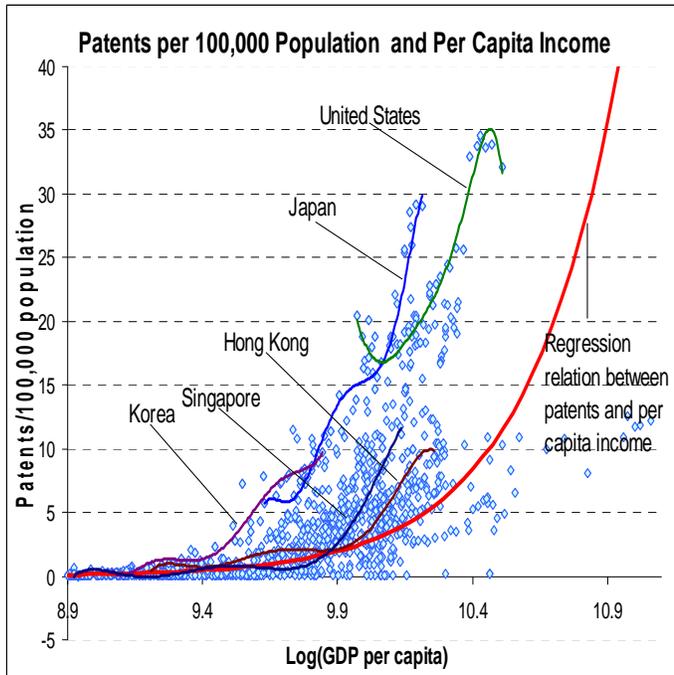
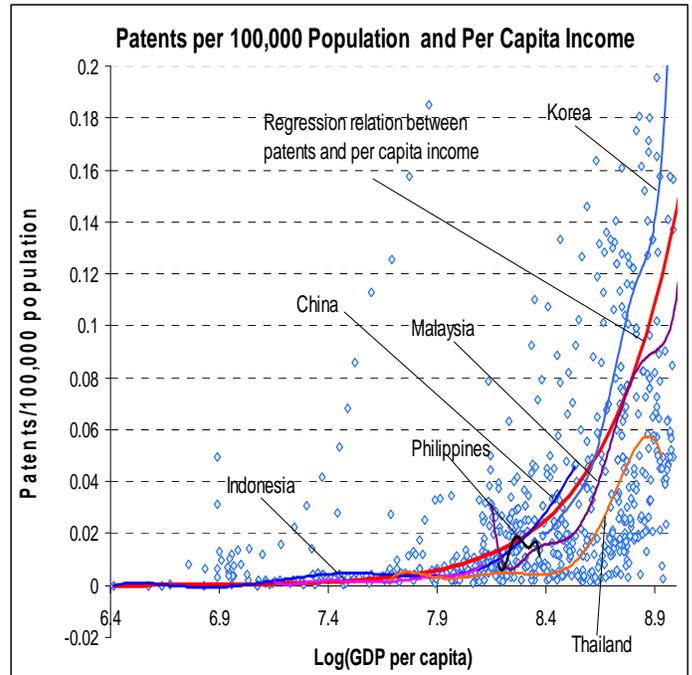


Exhibit 10



Source: USPTO and World Bank Development Indicators.

What factors determine the flow of innovation outputs in an economy? The large empirical literature estimating “knowledge production functions” in developed economies typically finds a strongly significant relationship between innovation inputs like R&D expenditure and innovation outputs such as patent counts.²⁸ Bottazzi and Peri (2005) study the short and long run dynamics of knowledge production in OECD countries by relating the flow of patents to domestic R&D flows and to the existing stocks of domestic and international knowledge (measured respectively by the stocks of patents accumulated in the country and in the rest of the OECD). The idea is that innovation depends not only on the current resources devoted to R&D in the country but also on knowledge spillovers from the entire stock of earlier knowledge accumulated in the world as a whole. Bottazzi and Peri find long run elasticities of patenting on R&D and the stock of foreign knowledge of around 0.8 and 0.6 respectively. Thus,

²⁸ For example see Hausman, Hall and Griliches (1984, 1986), Griliches (1990), Blundell, Griffith and Van Reenen (1995), Jaffe and Trajtenberg (2002).

in addition to domestic R&D, openness to foreign knowledge plays a big part in domestic innovation, a point that was also made in Section II above.

Recent World Bank research by Bosch, Lederman and Maloney (2005) appears to be a rare study that looks at the relationship between patenting and R&D worldwide, including developing economies. The study finds a significant relationship between patenting and R&D at the global level, although the estimated elasticity of patenting with respect to R&D for OECD economies (around 1) is substantially higher than among developing economies. The lower productivity of R&D spending in developing economies appears to be due to weaknesses in their national innovation systems. In particular the study finds that R&D productivity has a significant positive relationship with years of education, the quality of academic institutions, the quality of intellectual property rights and the level of collaboration between research institutions and the private sector, all factors which on average are substantially lower among developing than OECD economies. Among these factors, years of education and intellectual property rights appear to have the most significant impact on R&D efficiency.

In which technologies is East Asia innovating?

Is patenting in East Asia broadly diversified or concentrated in particular sectors? The USPTO classifies patents into one of around 480 technology classes. Exhibit 11 shows adjusted Herfindahl indexes of concentration across these technology classes for several major Pacific Rim economies. An index level of 1 means concentration in just one technology, while (in this case) an index of around 0.002 would mean equal distribution across all classes. The exhibit suggests that patenting in East Asian economies is considerably less diversified than in mature developed economies like Japan and the US.

Jaffe and Trajtenberg (1999) distill the lengthy list of USPTO patent classes into 6 broad groups: chemicals, computers and communications, drugs and medical, electrical and electronic, mechanical and all other. A major area of concentration in East Asia is electrical and electronics. The median share of patenting in this technology area for seven East Asian economies in 2002-04 is 38 percent, ranging from a low of 25 percent in Hong Kong to 45-50 percent in Taiwan (China) and Singapore. The second most important area of concentration is computers and communications, with a median East Asian share of 15 percent, ranging from a low of 12 percent for China and Malaysia to 25-30 percent for Korea and Singapore. The share of East Asian patenting in these two areas has generally risen since the early 1990s.

In part the high concentration of East Asian patenting in these sectors just reflects the high technological opportunity and propensity to patent in these sectors worldwide. But East Asian patenting in electrical and electronics (in particular) is also high relative to the world average share of patenting in this sector - in other words East Asian Revealed Comparative Advantage (RCA) indexes in this sector are generally substantially greater than one, reflecting world class levels of sophistication in specific areas of specialization, for example Korea in DRAM technology and LCD manufacture, or Taiwan (China) in the wafer foundry industry, testing and packaging services. By comparison most East Asian economies show a distinct revealed comparative disadvantage in the drugs and medical sector. (Exhibit 12).

Exhibit 11

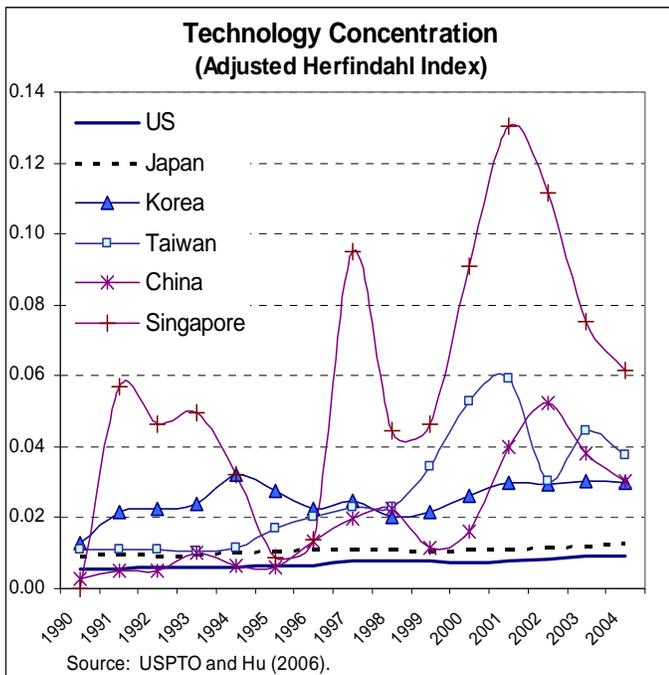
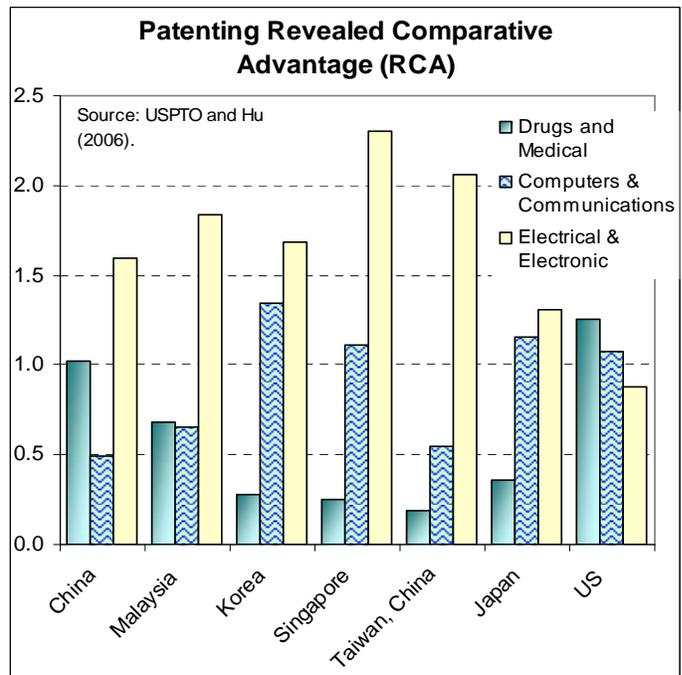


Exhibit 12



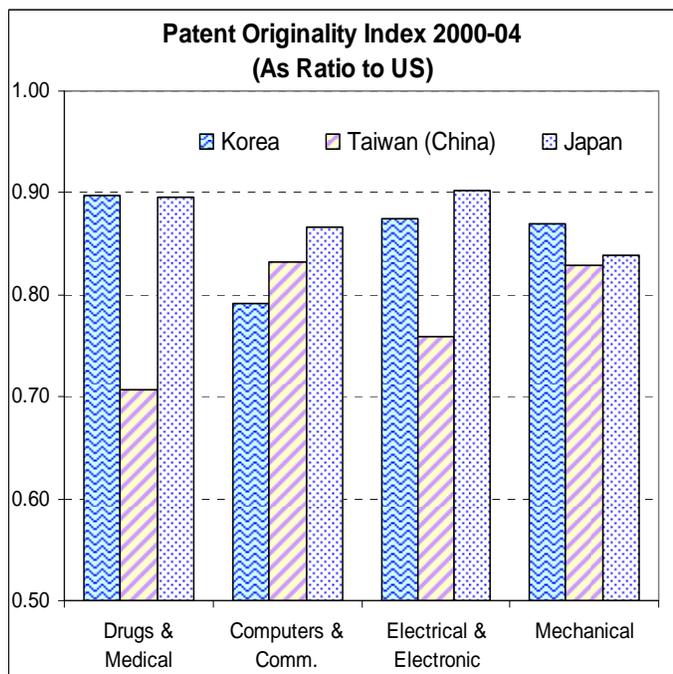
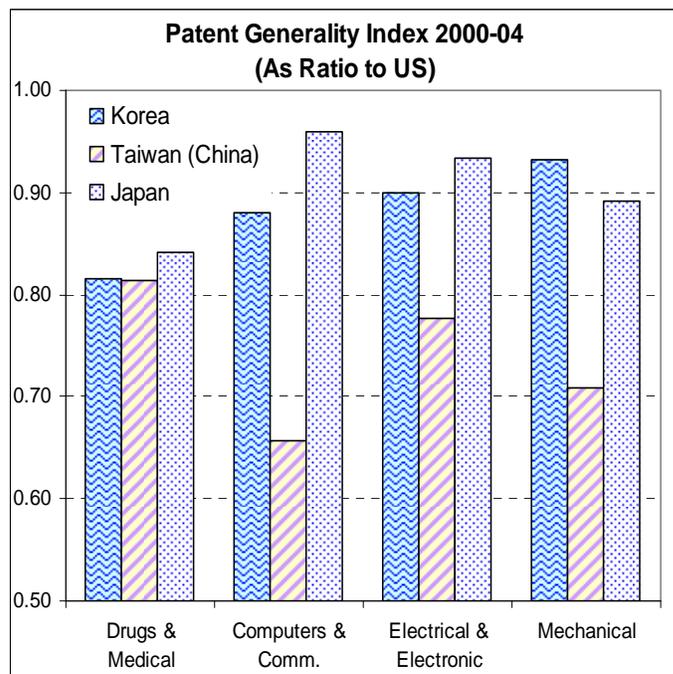
How Good is East Asian Patenting?

Although the volume of patenting in economies such as Korea and Taiwan (China) equals or exceeds that in most developed economies, is the same also true of the *quality* of their innovations? The technological or economic value of patents can vary enormously. In fact the distribution of patent values is highly skewed. A survey of the realized economic value of patents in Germany and the US, for example, found that the top 10 percent of patents accounted for over 80 percent of economic value. (Scherer and Harhoff, 2000). Thus a simple count of patents may not provide an adequate summary of the quality of the underlying innovations.

A particularly useful feature of patents is that they contain citations to the previous patents and scientific literature which define the “prior art” to which the patent is making an original contribution. Trajtenberg et al (1997) suggest measuring the quality of patents with indexes of patent “generality” and “originality” based on patent citations. A patent is said to have greater generality and impact if it is cited more often by a wider range of technology classes. A patent is said to be more basic or original if it cites a wide range of patent technology classes.

US patents generally have higher generality and originality indexes across all technology fields compared to Japan and other East Asian economies.²⁹ Exhibits 13 and 14 show that Japanese patents generally achieve quality ratings that are 80 to 90 percent or more of US quality ratings. Korea, in particular, is close to Japan in most technology areas, even matching or exceeding it in some. Taiwan (China) tends to achieve somewhat lower generality and originality scores, but still scores 70-80 percent of US levels.

²⁹ Some East Asian economies have few if any patents in some technology fields, resulting in few citations with which to compute generality or originality indexes. The discussion therefore focuses on Korea and Taiwan (China), economies with sufficient patenting activity for meaningful measurement.

Exhibit 13**Exhibit 14**

Source: USPTO and Hu (2006)

Knowledge Flows to, from and within East Asia: Patent Citations

Section II noted that knowledge flows from abroad play a crucial role in facilitating domestic R&D and innovation. In that discussion the evidence for knowledge flows was adduced indirectly, by looking at correlations between activities that are expected to facilitate knowledge flows – for example, foreign trade, FDI or technology licenses - and economic productivity. Section III cited econometric evidence on the spillover benefits for productivity growth in an individual economy from R&D in foreign countries. This section looks at evidence from patent citations, which provide a unique and more direct window onto flows of knowledge between inventors, firms and economies.³⁰

Exhibit 15 shows the share of various foreign economies in patent citations made by seven East Asian economies (as a group). The United States remains by far the largest source of citations for East Asian innovators, providing close to 60 percent, this proportion having risen slightly between 1992-94 and 2002-04. Japan is the second largest source, contributing close to 20 percent. (Korea is an interesting exception to this general pattern: its reliance on US citations is substantially lower than other East Asian economies – around 45 percent – while its reliance on Japan is higher, around 33 percent). The share of other ‘G5’ economies, defined here as comprising Canada, France, Germany, Italy and the U.K., is lower, less than 10 percent, having fallen over the last decade. Perhaps most interesting, the share of citations made by East Asian economies to other East Asian economies, while still low, is rising fast, picking up from 1.7 percent of citations in 1992-94 to 5.9 percent in 2002-04. Most of these intra-East Asian patent citations are to patents held by Korea and Taiwan (China), the two largest innovators in the

³⁰ The discussion draws on data from the NBER Patent Citations Database. See Footnote 30 for further details.

region. Exhibit 15 also indicates that the share of citations by inventors in an East Asian economy to patents granted to other inventors in the same economy (referred to as “compatriot citations”) is also rising, reaching 3.3 percent on average in 2002-04.

Exhibit 15

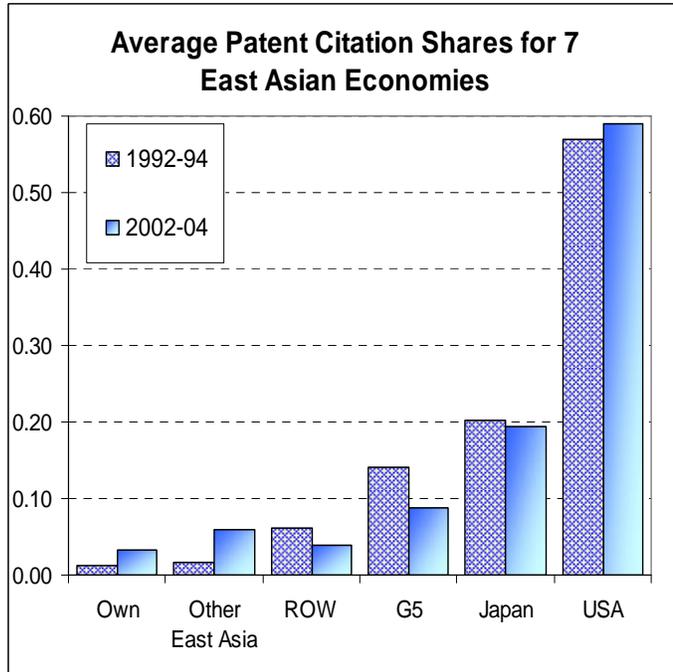
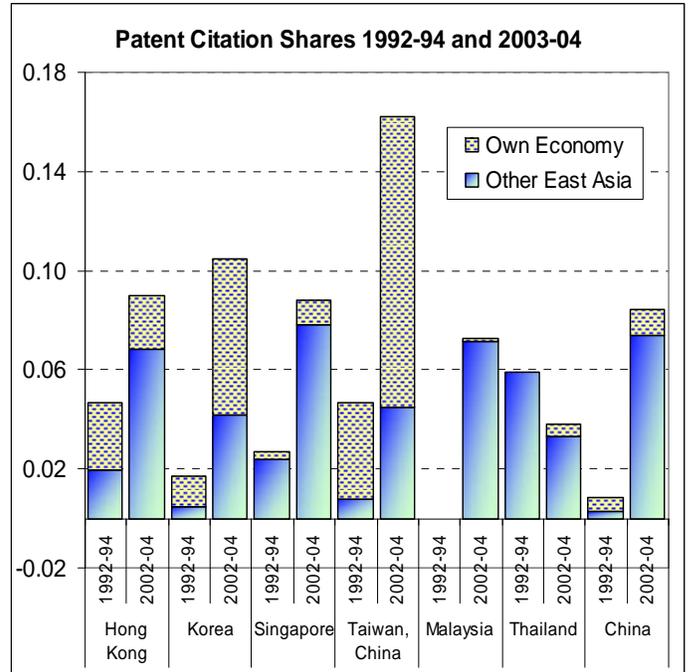


Exhibit 16



Source: USPTO and Hu (2006).

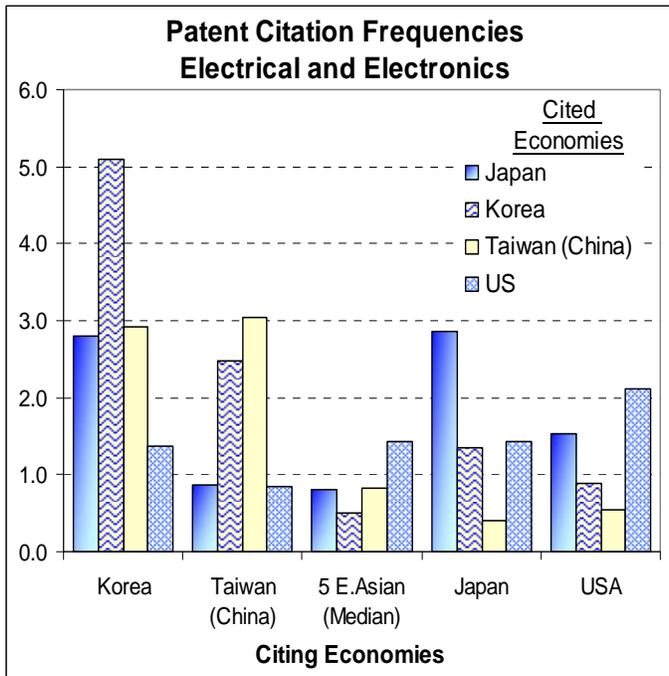
Exhibit 16 provides a closer look at the rise of intra-regional and compatriot knowledge flows for individual East Asian economies. The share of citations to other East Asian economies (typically to Korean and Taiwan (China) patents) is highest – around 7-8 percent - in China, Hong Kong, Malaysia and Singapore. The share of ‘own’ or ‘compatriot’ patents is highest in Korea (around 6 percent) and Taiwan (China), where it is already over 10 percent.

Such raw citation shares provide useful information on the gross flows of knowledge between economies, but say little about the *intensity* of knowledge relationships. It is not surprising that East Asian economies should have large shares of citations to US patents, simply because the US is by far the largest generator of patents worldwide, and thus of potential citations. Even Japan, which produces almost as many patents per capita as the US, still has over 40 percent of its citations to the US. Researchers have therefore developed a *citation frequency* measure of how intensively patents in one country cite patents from another after controlling for the size of the potential pool of citations between the two.³¹ In simple terms, it is the number of citations from country A to country B divided by the product of the potential number of citing patents in country A and potential number of citable patents in country B.

Exhibit 17 shows patent citation frequencies between the US, Japan, Korea and Taiwan (China) in the electrical and electronics technology field. There are several striking features. Each of these four economies cites compatriot patents from the same economy much more

³¹ For further detail see Jaffe and Trajtenberg (2002) and Hu (2006).

Exhibit 17



Source: USPTO and Hu (2006).

intensively than patents in the rest of the world. Thus, after controlling for the fact that the potential pool of citable electrical and electronics patents in Korea is much smaller than the potential pool in the US, Korean patents cite other Korean patents almost 5 times as intensively as they do US patents. This finding is consistent with earlier findings that there is a significant degree of *geographical localization* in knowledge spillovers. Thus Jaffe, Trajtenberg and Henderson (1993) found that even within the United States the frequency of citation from a patent in one American state to other patents from the same state is higher than from other states, while Jaffe and Trajtenberg (1998) confirmed that citation frequencies within OECD economies are much higher than the frequency of citation from one OECD economy to another.

Table 7. Citation Frequencies: Estimated Country-Pair Fixed Effects *

Citing Economies	Cited Economies			
	USA	Japan	Korea	Taiwan (China)
USA	1.00	0.57	0.38	0.29
Japan	0.46	0.80	0.44	0.23
Korea	0.46	0.70	1.16	0.69
Taiwan (China)	0.26	0.25	0.71	0.83
China	0.36	0.31	0.44	0.41
Hong Kong	0.45	0.41	0.42	0.40
Malaysia	0.44	0.32	0.53	0.57
Singapore	0.95	0.60	0.93	1.63
Thailand	0.66	0.33	0.27	0.10

Source: Hu (2006). * Normalized by "US citing US"=1

The main reason for geographical localization of knowledge spillovers is the *tacitness of knowledge*. Many types of information, for example the price of a commodity, can be easily codified and cheaply transmitted by electronic means. However complex scientific and technical knowledge often cannot be easily codified and can only be fully communicated if accompanied by face to face interaction. Tacitness and geographical localization help explain the economic usefulness of cities and industrial clusters, which facilitate face to face interactions and knowledge spillovers. At the national level these findings provide more evidence for the value of domestic R&D and innovation efforts,

since they suggest that it is easier for local residents to absorb the knowledge spillovers from local innovations than it is from foreign ones. Among other important research results, Jaffe, Trajtenberg and Henderson (1993) found that localization within US states fades away over time, while Audretsch and Feldman (1996) found that geographical clustering is greatest in industries with high R&D intensity and high employment of skilled labor, as well as in industries at an early stage of their life cycle, when more of the knowledge about that industry is still in the heads of skilled workers and less of it has been codified in manuals and protocols.

Exhibit 17 above also provides evidence for the high intensity of intra-East Asian cross-border knowledge flows. The citation frequency from Korea to both Taiwan (China) and Japan

patents is more than twice as high as citation frequency for US patents. Reciprocating, Taiwan (China)'s citation frequency to Korea is also near three times its frequency with Japan and the US, while Japan's frequency to Korea is almost as high as its citation frequency to US patents. These trends again confirm the growing regional dimension in East Asian knowledge flows.

A more rigorous analysis of citation frequency uses the double exponential model of knowledge diffusion introduced by Caballero and Jaffe (1993). Hu (2006) estimates this model for East Asian economies to derive more refined estimates of citation frequencies between countries after taking into account the 'technological proximity' between pairs of economies³², lags between citing and cited patents, obsolescence and fixed effects for different technology classes. Table 7 shows these estimates normalized relative to the citation frequency of US patents citing other US patents, which is set equal to one. The results for Korea, Taiwan (China) Japan and the US are similar to those for 'raw' citation frequencies discussed above. Singapore shows an exceptionally high citation frequency to Taiwan (China), and also to Korea, which significantly exceed or equal (also high) citation frequencies to Japan and the US. China and Malaysia's citation frequencies to Korea and Taiwan (China) also exceed those to Japan and the US. (An Appendix to this paper provides a more detailed outline of the estimated knowledge diffusion model).

V Policy Considerations

This section discusses policies and institutions that may help foster domestic innovation as well as absorption of knowledge from abroad. It briefly reviews differences in the quality of these policies and institutions across East Asian economies.

Business Environment for Innovation

If R&D and other innovation activities undertaken by firms are best viewed as a form of capital investment, it is not surprising that they are affected by many of the same factors as overall business investment.

Macroeconomic stability. Persistent macroeconomic instability is among the factors commonly found among the most harmful to private investment, and it is also found to have a clear adverse impact on R&D intensity. Lederman and Maloney (2003) find that macroeconomic volatility as measured by the standard deviation of per capita GDP growth has a very significant negative relation with R&D intensity. For OECD countries, Jaumotte and Pain (2005a) find that low and stable inflation has a positive influence on the rate of growth of R&D stocks.

Cost of capital and financial development. The cost of capital, the availability of credit and the level of development of the financial system are also important for innovation. Jaumotte and Pain (2005a) find that the user cost of capital has a significant negative relation with the growth of R&D stocks in OECD countries, while Lederman and Maloney (2003) obtain a similar result for a real interest rate measure with respect to R&D intensity in a set of both developed and developing countries. The quantity of credit and financial sector depth are also important influences on innovation. A well developed financial sector and capital market help meet the widely different financing needs of more or less risky short term and long term innovation

³² Technological proximity is defined as the correlation between the technology vectors of two economies, each vector being defined as the shares of total patents taken out by the economy in 428 different technology classes.

projects undertaken by firms. As noted, Aryaggari et al (2006) find availability of finance from sources external to the firm to have a strong association with broader measures of firm innovation in developing countries. Jaumotte and Pain arrive at similar conclusions for growth in R&D stocks in OECD countries with respect to corporate profits (firm internal finance), credit to the private sector from financial institutions and stock market capitalization. Table 8 uses credit to the private sector as a rough indicator of financial sector development, indicating significantly lower financial depth in various of the middle income South East Asian economies than in the NIEs.

Table 8. National Innovation Systems and Business Environment – Selected Variables

	Credit Market Depth 2000- 04 (1)	Starting a Business (Days) (2)	Average Years of Schooling 2000 (3)	Researchers per million 2003 (4)	Quality of Scientific Research Institutions (5)	University- Industry Research Collaboration (5)	Intellectual Property Protection (5)	Phone Subscribers per 1000 2003 (6)
East Asia (9)	102	40	7.6	1375	4.5	4.1	4.3	878
NIEs	125	22	9.2	3165	5.2	4.7	5.1	1475
Hong Kong	153	11	9.5	1564	4.9	4.1	5.0	1640
Korea	98	22	10.5	3187	5.1	4.8	4.5	1240
Singapore	115	6	8.1	4745	5.5	5.0	6.1	1284
Taiwan, China	135	48	8.5	..	5.2	4.9	4.9	1735
SE Asia	75	66	6.6	210	4.1	3.6	3.8	398
Indonesia	20	151	4.7	207	3.9	3.4	3.2	127
Malaysia	141	30	7.9	299	5.0	4.7	5.1	642
Philippines	38	48	7.6	48	3.3	2.7	2.8	322
Thailand	102	33	6.1	287	4.0	3.6	4.1	499
China	118	48	5.7	663	3.8	3.9	3.2	413
High Income (21)	112	20	9.5	3616	5.1	4.4	5.5	1392
Japan	100	31	9.7	5287	5.6	4.6	5.3	1151
USA	249	5	12.3	4484	6.4	5.7	6.4	1175
Latin America (11)	36	67	6.7	300	3.5	3.0	3.1	409
Emerg. Europe (9)	29	30	8.7	1503	4.0	3.1	3.3	850

(1)Credit to Private Sector as % of GDP. (2) World Bank. Doing Business 2005. (3) Source: Barro and Lee (2000).

(4) UNESCO (2006). (5) Source: Global Competitiveness Report 2005. Index ranging from 1 (weakest) to 7 (strongest).

(6) Fixed Line and Mobile subscribers per 1000 population. All regional data are simple averages.

Aghion, Angeletos, Banerjee and Manova (2005) emphasize that credit availability and financial development are particularly important when firms are in a volatile macroeconomic environment. Firms with significant credit constraints will be less able to overcome short term liquidity pressures during economic downturns, and so will undertake less long term R&D. Long term credit allows firms to look beyond cyclical and liquidity pressures to pursue longer term innovation. Panel data for OECD countries shows that the interaction term between financial development and volatility has a significantly positive impact on the ratio of R&D to total investment spending.

Openness. The earlier discussion of imports as a channel for technology transfer suggests that excessively restrictive trade policies can prove a significant barrier to international technology transfer. Preferential trading arrangements that create a bias against trade with R&D rich Northern economies will also tend to choke off knowledge transfers and spillovers, which (following the results of Schiff, Wang and Olarreaga, 2002) may be especially detrimental to the development of R&D intensive industries. Hoekman, Maskus and Saggi (2005) point out,

however, that these arguments for open trade policies are not entirely unconditional. If development of a national industry creates localized knowledge spillovers, there may be a rationale for intervention. This was form of infant-industry argument was one of the justifications for import-substitution strategies in many developing countries in the 1950s and 1960s. Nevertheless, trade restrictions may not be the most effective way of fostering domestic R&D, industrial development or spillovers, since they create new distortions, reward domestic firms whether they innovate or not, and have a high cost, not least by restricting international knowledge inflows. More direct policies to subsidize domestic R&D, improve the investment climate and strengthen education are likely to prove superior.

Competition. As with trade openness, the question whether greater competition in domestic product markets serves to foster innovation does not have an entirely simple answer. A survey of OECD countries by Ahn (2002) comes to the agnostic conclusion that “empirical evidence does not support the view that market concentration is an independent and significant determinant of innovative behavior and performance.” Although other studies (for example Nickell, 1996, and Blundell, Griffith and Van Reenen, 1999) have pointed to a positive correlation. Evidence is much thinner for developing economies, but Ayyagari et al (2006) also find a positive relation between several competition indicators and their broad measure of firm dynamism in low and middle income economies.

Aghion, Bloom, Blundell, Griffith and Howitt (2005) observe that greater product market competition between incumbent firms could have different effects that both discourage and promote innovation. In industries where the existing level of competition is low and firms have similar levels of technological capability, more competition may promote innovation by giving the innovating firm a competitive advantage. On the other hand, in industries where there is already high product market competition and one firm has a large technological lead over others, a further increase in competition may discourage innovation by lagging firms because it reduces the rewards for trying to ‘catch-up’. The study finds strong evidence for such an ‘inverted U curve’ in multi-industry panel data for UK firms. Aghion, Blundell, Griffith, Howitt and Prantl (2006) argue that entry of technologically advanced firms into an industry can also have a similar dual-edged effect on innovation, tending to stimulate innovation when incumbent firms are close to the global technology frontier, but discouraging it when they are technological laggards.

Given the limited empirical evidence, it is probably unwise to draw firm conclusions for policy in East Asian or other developing countries. But a few observations can be hazarded. First, increased competition has many potential benefits effort economic performance other than the impact on innovation, for example on firm efficiency and overall productivity growth. (Ahn, 2002). Conclusions about the role of competition policy need to be based on an assessment of all of these effects. Second, the balance of empirical work cited finds a positive association between more competition between incumbent firms and innovation. While the study by Aghion, Bloom, Blundell, Griffith and Howitt (2005) reaches more qualified results, it too suggests that more competition is favorable for innovation when competition is low to start with – that is, when lack of competition is most likely to be of concern to policymakers.

Turning to new firm entry, the interesting findings by Aghion, Blundell, Griffith, Howitt and Prantl (2006) for the U.K. obviously need to be buttressed by more empirical work across a wider range of countries (including developing countries). There are several hypotheses that need further empirical testing. One is that opening up to entry by technologically sophisticated competitors may be especially beneficial for innovation by incumbent firms in advanced

emerging economies like Korea, Taiwan (China) and Singapore, where many key sectors now function close to the global technology frontier. This might also be the case in fast moving middle income economies that aspire to follow in the tracks of the advanced emerging economies. By the same token the study suggests the possibility that opening up to technologically sophisticated firms could have a depressing effect on innovation in economies and sectors that are far from the global technological frontier.

However a number of other considerations do need to be kept in mind in drawing policy conclusions from these findings. First, new firm entry could lead to gains in productivity and consumer welfare due to replacement of low productivity by high productivity firms and the reallocation of resources to more productive uses. Bartelsman, Haltiwanger and Scarpetta (2004) note that the process of creative destruction – the entry of new firms and the exit of less efficient ones – contributes from 20 to 50 percent of total labor productivity growth among firms in 10 developed and 14 developing economies. In contrast to Aghion et al, they also find a positive relation between the pace of creative destruction (i.e. of net entry) and productivity growth in already existing (incumbent) firms. They suggest that increased contestability of markets by new entrants induces incumbent firms to perform more efficiently. Second, new entry by technologically sophisticated firms is also likely to facilitate vertical technology transfer to local suppliers. This discussion suggests that even in less developed economies blocking off entry by sophisticated foreign firms is unlikely to be the most efficient economy-wide way of promoting technological development and productivity growth. As with trade, more direct fiscal or other measures may provide superior instruments to foster domestic R&D and innovation. We return to such instruments later in this section.

Intellectual Property Rights (IPR) regime. A fifth important factor for innovation is the intellectual property rights (IPR) regime, although theoretically the direction of the effect is ambiguous. On the one hand a weak IPR regime hampers firms from appropriating the returns from R&D. However IPRs themselves create an economic distortion by granting a temporary monopoly to innovators. This may make it more difficult for other firms to access knowledge they need for their own innovation activities. IPRs may also dampen innovation if they reduce competition in product markets and if less competition tends to reduce innovation.

Which of these effects prevails is an empirical question. Table 8 shows that the quality of the IP regime is rated as significantly weaker in China and several South East Asian economies than in the NIEs. Lederman and Maloney (2005) find that stronger IPRs have a highly significant positive impact on R&D intensity in their sample of developing and developed economies, while Bosch, Lederman and Maloney (2005) find that IPR quality has a significant positive impact on the productivity of R&D, as measured by patents per dollar of R&D. For OECD countries, Jaumotte and Pain (2005a) however find that IPRs have little discernable influence on the growth of R&D stocks, although they do influence the flow of patenting. They suggest that in OECD countries IPRs influence the propensity to patent out of the underlying stream of innovations, but not that flow itself. The lack of influence on OECD R&D may reflect the fact that there is much less variation in the quality of IPR regimes across OECD countries than in the world as a whole. The coefficient of variation in OECD countries for IPR regimes shown in Table 8 is only one third as large as in the whole sample.

Recent research suggests that IPR regimes may influence not only indigenous R&D and innovation, but also the scope of countries' interactions with the outside world, which, as this paper has stressed, are a primary means of absorbing new knowledge in most developing

countries, through trade, FDI, licensing of foreign technologies or other means. Fink and Maskus (2005) note that the potential impact of IPRs on inward technology transfer is also theoretically ambiguous: stronger IPRs will improve incentives for a foreign IPR holder to enter the domestic market, but will also increase its market power. While foreign technologies become more available in the domestic market, domestic firms are less able to imitate them. The net effect on the volume of international transactions and on domestic productivity growth is an empirical question, the answer to which may differ across countries and sectors.

Fink and Maskus (2005) also note recent studies that find a significant positive link between stronger IPRs and international trade. Stronger patent rights appear to have the most significant influence on the propensity of multinational companies to export in the case of large middle income economies, i.e. those which pose a greater threat of imitation and reverse engineering. The evidence on IPRs and foreign direct investment is less conclusive. However there is some evidence that IPRs are a significant consideration for FDI location decisions among middle income countries. Foreign firms may be also be more likely to invest in local production and R&D rather than in distribution facilities when there are stronger IPRs. Finally there is clear evidence that stronger IPRs have a significant positive impact on international technology licensing (as measured by licensing royalty payments). Licensing is clearly sensitive to the lower contract enforcement costs provided by a stronger IPR regime.

Information and Communications Technology (ICT) Infrastructure. Availability of good ICT infrastructure is important in fostering innovation, both by facilitating cheap circulation of disembodied knowledge across and within national boundaries, as well as by reducing the transactions costs of international trade and foreign investment flows. Rapid advances in ICT services in developing countries have been driven in part by the liberalization of telecom markets and regulatory reform in recent decades. Nevertheless there remain wide disparities in ICT development across East Asia. (Table 8).

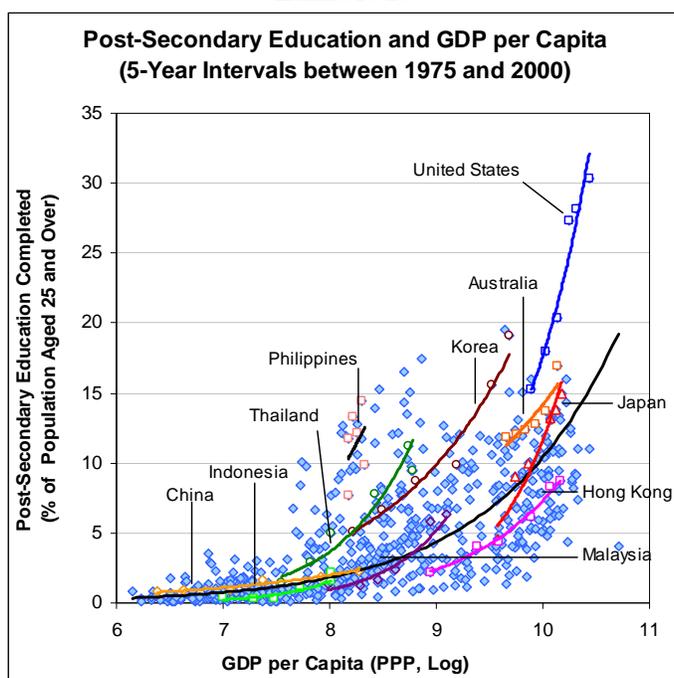
Human Capital Development

Education and other forms of human capital development provide a fundamental underpinning for both domestic innovation activity and for the learning capacity of the economy. Table 8 shows that South East Asian economies and China possess around 3 years fewer average years of schooling than the NIEs. Exhibit 18 shows that the proportion of adults with higher education tends to rise more than proportionately with income. Some countries such as Korea have increased higher education even more rapidly, while others have lagged.

There are also sharp differences in the quality of education. The four East Asian NIEs achieved the highest math and science scores out of 45-46 economies participating in 2003 TIMMS exercise.³³ On the other hand, the Philippines was in the bottom 5 for both math and science, while Indonesia was in, or not too much above, the bottom ten. Similarly, in the OECD's 2003 Program for International Student Assessment (PISA) for mathematics proficiency, Korea and Hong Kong (China) were in the top 5 in a sample of 40, while Thailand and Indonesia were in the bottom 5. There are also wide differences in the extent and quality of tertiary and specialized scientific and technical education, as reflected in the numbers of researchers per million shown in Table 8. This measure averages over 3000 in the NIEs, and fewer than one tenth as many on average in South East Asian economies.

³³ TIMMS is the Trends in International Mathematics and Science Study.

Exhibit 18



Source: Barro and Lee (2000) and World Bank.

Government Support for Innovation Activity

So far this section has mostly covered broad policy areas like maintenance of macroeconomic stability, financial sector development and human capital development that, while they are expected to promote innovation and technology transfer, are also expected to have other wider economic and social benefits. Now we look at more specific policies that aim to foster innovation through targeted fiscal incentives or regulations. The theoretical rationale for direct public interventions of this type derives from the possibility that they might help offset market failures associated with knowledge, for example non-excludability, which make it difficult for private firms to appropriate all the returns from their R&D

investments, leading to less than optimal innovation activities. Such problems are likely to be particularly significant for basic research that provides the early seeds for a variety of innovations by many firms, or which help countries better access the global pool of knowledge. We look at four types of policies.

Support for science and university/public sector research. As Table 5 above indicates, the public sector in developed countries provides about one third of R&D funding, on average 0.6-0.7 percent of GDP, including funding for basic scientific research undertaken by universities or public sector research laboratories and institutes. In East Asia, public funding for R&D reaches this level of GDP only in a few advanced economies like Korea, Singapore and Taiwan (China).

There is a good deal of evidence for the positive effect of R&D funded or performed by universities and the public sector on both overall productivity and on business R&D. As noted above, Guellec and Pottelsberghe de la Potterie (2004) find the positive impact of university and public R&D stocks on productivity growth in OECD countries to be even larger than that of business R&D stocks. Jaumotte and Pain (2005b) also find that non-business R&D spending has a significant impact on growth in business R&D stocks in OECD countries, with a couple of qualifications. First, the impact of public and university R&D is likely to depend on the quality of links between these sectors and the business R&D sector, which uses the results of more basic research to develop commercially valuable products. Second, a greater volume of public sector R&D can “crowd out” business R&D by pushing up wages for scientific and technical staff. The latter could be a particular concern in developing countries where such specialized skills are in scarce supply. At least in OECD countries, the overall impact of non-business R&D on business R&D remains positive, even after taking crowding-out effects into account.

As regards evidence for developing countries, Lederman and Maloney (2003) find that the perceived quality of research institutions such as universities and public research institutes has a significant positive impact on overall R&D intensity in both developed and developing countries, as does the perceived quality of the interaction between these institutions and the private sector. Bosch, Lederman and Maloney (2005) find that these two factors also have a significant impact on the productivity of R&D in developed and developing countries. Table 8 above shows that there are significant disparities in the quality of scientific/academic research institutions and the quality of university-industry research collaboration, with the NIEs and Malaysia scoring significantly higher than other South East economies and China. In addition, policy makers also need to ensure that public research funding is allocated using transparent, competitive and merit-based procedures, according to criteria which strike an acceptable balance between short term commercial interests and longer term needs.

Fiscal subsidies and tax incentives for business R&D. Many countries also devote significant fiscal resources to subsidies or tax incentives for business R&D. Although there is often a sound theoretical rationale for such measures, there are also serious informational and incentive problems in implementing such policies. A limited amount of empirical work does not so far yield much of a consensus on their effectiveness.

Among practical difficulties two stand out. First, governments are unlikely to have any special information about which sectors might yield the largest knowledge spillovers from innovation, and which therefore merit help. Government policies to ‘pick winners’ could then lead to outcomes that are worse than those resulting from private decisions unconcerned about externalities and market failures. (Pack and Saggi, 2006; Klimenko, 2004). Noland and Pack (2003) conclude that preferential industrial policies in Japan tended to concentrate on declining sectors rather than on industries experiencing rapid technological change or increasing returns, and had no noticeable impact on national or sectoral rates of total factor productivity growth. For Korea they conclude that “the evidence does not support the notion that selective intervention had a decisive (or even necessarily a positive) impact on the Korean economy.” Rodrik (2004) observes that a modern or “new” industrial policy should no longer aim to “pick winners” or sectors, but should instead target key activities that are underprovided because of market failures, for example through a generalized tax credit that does not discriminate across sectors, or support for adaptation of foreign technologies to local conditions.

The second difficulty is that fiscal incentives for innovation can easily become a gateway for corruption and rent-seeking. It is thus not clear if the social gains from fiscal incentives would offset all the compliance and administrative costs associated with it.

In a review of the empirical literature, Garcia-Quevado (2004) finds there is not yet much consensus on the effectiveness of public R&D subsidies. Some studies find a significant positive impact on business R&D, but that this declines after a point and even becomes negative (so that subsidies substitute for private financing that would have been used in the absence of the subsidy). Jaumotte and Pain (2005b) find that R&D subsidies have a slightly negative impact on growth in business R&D stocks, evaluated at the mean for their sample of OECD countries. The evidence seems clearer on the effectiveness of R&D tax credits. Bloom, Griffith and Van Reenen (2000) find that changes in R&D tax credits have a large impact on the user cost of capital for R&D and that the long run elasticity of business R&D with respect to tax incentives may be substantial, on the order of 1. Such studies do not necessarily prove that tax credits would be welfare enhancing overall, though. A full cost benefit analysis would need to account

for the value of alternative uses for foregone tax revenues, the administrative costs of the R&D tax credit system and the various new distortions the tax scheme could itself introduce.

Fiscal Incentives for FDI. This section concludes with a look at policies to attract FDI and to enhance the benefits of FDI for the domestic economy, which are often rationalized on the basis of the technology transfers FDI is expected to bring. A general point that emerges from the large research literature on the determinants and consequences of FDI³⁴ is that the fundamentals that are important for encouraging and benefiting from capital investment as such - a friendly business climate, macroeconomic and political stability, good quality infrastructure, a relatively open trade policy regime and availability of relatively skilled labor – are also important for FDI.

Governments also use targeted policies to attract FDI, such as tax incentives, import duty exemptions, or land and power subsidies. If FDI creates positive spillovers for the economy, there is a theoretical rationale for some government intervention. However, as noted, the evidence for horizontal FDI spillovers is mixed, especially in developing economies. There is evidence that domestic firms with high human capital and R&D receive more spillovers, and also that foreign firms that do R&D in the host country generate more spillovers. But this provides a rationale for strengthening education, and perhaps for incentives to R&D done locally (whether by local or foreign firms) rather than for subsidizing FDI. Given stronger evidence for vertical technology transfer between MNCs and developing country suppliers (Blalock and Gertler, 2005), it is clear that policies that *discourage* FDI carry a high price tag in forgone technology and, all else being equal, should be avoided. However this type of vertical technology transfer is internal to supply chain transactions and the benefits are realized by the supplier and the buyer. By itself such technology transfer does not provide a rationale for intervention.³⁵

Overall, empirical research provides little conclusive evidence to warrant substantial fiscal incentives to promote FDI on welfare grounds. Nevertheless, in the mid-1990s more than 100 countries offered such incentives, a trend that continues. A survey of 45 developing countries found that 85 percent offered some kind of tax holiday or reduction of corporate income tax for foreign investment. (World Bank, 2005). How effective are such measures? Most studies show that such incentives are only one among a set of relevant investment climate variables (of the sort outlined in the last paragraph). Indeed, the World Bank's Investment Climate Surveys show that unreliable power supply, weak contract enforcement, corruption, and crime can impose costs several times greater than taxes. A MIGA survey of 191 companies with plans to expand operations found that only 18 percent in manufacturing and 9 percent in services considered grants and incentives to be influential in their choice of location. Of 75 Fortune 500 companies surveyed, only four identified them as influential.³⁶

This does not mean that fiscal incentives are unimportant. When other fundamentals are satisfied, they play a role in the choice of location. Incentives can influence the choice of

³⁴ Recent surveys of this work include Balasubramanyam, et al (2001) and Hanson (2001).

³⁵ Blalock and Gertler (2005) argue that there may nevertheless be an externality associated with vertical technology transfers that warrants some public intervention. If a MNC transfers technology to only one supplier it could enhance the market power of and be "held-up" by that supplier. Thus the MNC has an incentive to transfer technology to several competing suppliers, leading to a more productive supply base and lower prices. However the MNC cannot prevent the new suppliers from also selling to the MNCs' competitors, who will then be in a position to increase competition and lower prices in the downstream market. The original MNC would not however take all these social welfare gains into account and may transfer a less than optimally amount of technology to suppliers.

³⁶ See World Bank (2005); MIGA (2002); Morisset (2003); Farrell, Remes and Schulz (2005); and Oman (2000).

location within regional groups like the EU, NAFTA or ASEAN, and also the kind of FDI that is attracted. However, incentive packages can be quite costly through loss of tax revenue and hence of resources for government functions. In Tunisia the costs of fiscal incentives amounted to almost 20 percent of total private investment in 2001. The package India offered Ford in 1997 was estimated to cost \$200-420,000 per job.³⁷ Fiscal incentives also distort resource allocation, for example by discriminating against local investors, or by attracting short-term investors, and are often costly to administer. Tax holidays or temporary rebates in particular tend to attract investments typical of “footloose” industries and to reward the forming of new companies rather than continued investment in existing ones. Discretionary incentive regimes create uncertainty for investors and foster corruption, especially in countries without strong institutions.

Given these costs, there has been a recent trend to eliminate or simplify tax incentives. Simple, predictable and non-discretionary incentive schemes will be attractive to investors even if they are not excessively generous, while being less costly for host countries. Governments also increasingly try to attract FDI through investment promotion agencies (IPAs) that address possible information failures. There are now at least 160 national and more than 250 subnational IPAs, compared with only a handful two decades ago. These agencies play a variety of roles—information dissemination; image building; investment facilitation; investment generation; investor monitoring and aftercare; and policy advocacy.

Policies to enhance FDI spillovers. Governments use a variety of trade related investment measures or TRIMs to try and enhance positive spillovers from FDI. Domestic content requirements aim to increase vertical technology transfer by requiring foreign firms to buy more inputs from local producers, although this may create a disincentive for FDI in the first place. Such requirements in the auto sectors in Chile and Australia resulted in large inefficiencies. (World Bank, 2005). McKinsey Consultants estimate that content requirements made cars produced in China 20-30 percent more expensive than in the U.S. On the other hand the lack of or phasing out of local content requirements in the consumer electronics sector in China and the Mexican auto sector has not hindered the rapid development of sophisticated supplier industries in these countries. (Farrell, Remes and Schulz, 2005).

Mandated joint ventures or local equity participation regulations also aim to encourage technology spillovers but can simply make foreign firms wary about using their most advanced processes, reducing potential spillovers. Because of local partnership rules international investors in the auto sector in China were reluctant to use the latest processes, so that manufacturing methods have tended to lag industry standards by about 10 years. Kodak invested six times more in its one wholly owned subsidiary in China than in its various joint venture partners. Its subsidiary produced its most advanced film and camera technologies, while the joint ventures produced only conventional film. On the other hand multinationals are often quite willing to form joint ventures with local partners when this makes economic and strategic sense, even without regulations, for example in the retail sector in Brazil and Mexico. In recent years countries have tended to adopt more general strategies to work with foreign affiliates and local firms to overcome information and cultural barriers. These programs are often combined with incentives to help the domestic suppliers meet the production standards demanded by foreign investors. This approach has been followed in economies such as Ireland, Malaysia, Singapore, and Taiwan (China). (World Bank, 2005).

³⁷ Gorg (2003).

Appendix: Estimating the knowledge diffusion model

To investigate the intensity of knowledge flow in East Asia and beyond, the following double exponential knowledge diffusion model is estimated:³⁸

$$CF_{iT,jtg} = (1 + TD_{iT,jtg})\alpha(ij, T, t, g) \exp(1 - \beta_1(T - t))(1 - \exp(-\beta_2(T - t))) \quad (\text{A.1})$$

where i and j denote citing and cited countries respectively; citing patents are granted in year T and cited patents in year t ; g is one of the six main technological fields. The left hand side is the citation frequency of patents of country i granted in year T citing country j 's patents that are granted in year t in technological area g . It is computed as:

$$CF_{iT,jtg} = \frac{C_{iT,jtg}}{N_{iT}N_{jtg}}$$

i.e., the number of cites scaled by the numbers of potentially citing and citable patents. It measures the empirical frequency of a patent from the group defined by iT citing a patent from the group with the characteristics of jtg .

The probability that a patent is cited by another patent depends on among other things, the likelihood that the cited patent comes to the knowledge of the inventor of the citing patent and the relevance of the knowledge embodied in the cited patent to the citing patent. The former increases with the lag between the grant dates of the citing and cited patents ($T-t$) - the longer the cited patent has been around, the more likely it becomes known to the inventor of the citing patent, whereas the latter diminishes with the lag. As new knowledge emerges and/or as the wide adoption of the old knowledge reduces the economic rent accruable to the proprietary knowledge embodied in the cited patent, the likelihood that the cited patent remains relevant and prior art to a potential citing patent is reduced. The double exponential model in equation (A.1) captures these two processes with β_1 measuring the speed of obsolescence and β_2 the speed of diffusion.

The first term of the right hand side of equation (A.1) contains the technology distance between the citing patents and the cited patents. The technology distance variable is defined as:

$$TD_{iT,jtg} = V_{iT}'V_{jtg}$$

where V_{it} is a 428-element vector of patent class shares of country i 's USPTO patents granted in year t . TP is bounded between 0 and 1 and monotonically increasing in the similarity between two economies' patent portfolio, which we use to measure the technological proximity between the two economies. The closer the potentially citing patent is to the potentially cited patent in the technology space, the easier it is for the citing patent to capture knowledge spillover from the cited patent and therefore the likelihood of citation increases. Finally, $\alpha(ij, T, t, g)$ represents a number of fixed effects we are interested in estimating:

$$\alpha(ij, T, t, g) = \exp\left(\sum_i \sum_j \alpha_{ij} D_{ij} + \sum_T \alpha_T D_T + \sum_t \alpha_t D_t + \sum_g \alpha_g D_g\right)$$

For each set of fixed effects (D 's), one reference case is left out in the estimation. The citing-cited country pair specific effect is estimated with the α_{ij} 's. For example, with U.S. citing U.S. as the reference group α_{TWUS} would measure how much more intensively Taiwan cites the U.S. relative to the U.S. cites itself. If the coefficient is estimated to be say 0.5, then it would

³⁸ The model was first proposed and estimated in Caballero and Jaffe (1993) and was later estimated in Jaffe and Trajtenberg (1998) and Hu and Jaffe (2003).

imply that Taiwan cites the U.S. half as frequently as the US does. The citation frequency may also vary with the grant year of the citing patents; and this is captured by α_t 's. With both the effects of citing year and citation lag included, we are not able to estimate a full set of cited year effects of α_t 's. Instead we group the cited year t 's into groups and estimate the group effects. Lastly, we also allow the average citation frequencies of the six main technology fields to differ.

Instead of estimating all the country pair effects in my citation database, which would lead to an explosion of the number of parameters to be estimated and overtaxing the data's identifying capability, we choose to be selective in the number of citing and cited countries to model. For cited countries, we include U.S., Japan, G5, Korea and Taiwan in view of their dominance in patent numbers and as a source of citations. All seven East Asian economies and US and Japan are included as citing countries, the latter for comparison and benchmarking purposes.

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